CCSF NUTRITION TEXTBOOK: INTRODUCTION TO NUTRITION — SCIENCE AND EVERYDAY APPLICATION



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Introduction to Nutrition — Science and Everyday Application

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CHAPTER 1: INTRODUCTION TO NUTRITION

This unit introduces foundational concepts in nutrition, emphasizing the complex relationship between food, health, and personal behaviors. Students will explore the science of nutrients and calories, the importance of food quality, and how nutrition impacts overall health. The unit also delves into psychological and social factors influencing eating habits, energy balance, and various diet approaches. Through research highlights and reflective diet analysis activities, learners will develop critical thinking skills and a balanced philosophy toward food, fostering a holistic understanding of nutrition and well-being.

Learning Objectives:

By the end of this unit, students will be able to:

1. Define key nutrition concepts, including nutrients, calories, and units of measurement.
2. Explain the relationship between food quality, nutrient intake, and health outcomes.
3. Describe the molecular basis of nutrition and how it relates to bodily functions.
4. Analyze personal eating behaviors and food choices in the context of energy balance.
5. Compare and contrast different diet types and their potential impacts on health.
6. Explore approaches to healthy eating philosophies such as Health At Every Size® and intuitive eating.
7. Apply research findings, such as Maslow's Hierarchy of Needs and risk factors, to nutrition and health contexts.
8. Reflect critically on personal dietary habits through structured diet analysis activities to support informed and mindful eating decisions.

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1.1: Basic Concepts in Nutrition

This section introduces students to the foundational principles of nutrition science, focusing on the essential concepts necessary for understanding the role of food in human health. Students will explore how we think about food, the importance of food quality, and the biological basis of nutrition, including molecules, nutrients, and calories. The unit also examines how nutrition connects to broader health outcomes and risk factors. Through a combination of scientific content and reflective practice, students will begin developing the critical thinking and self-awareness necessary to engage with nutrition both academically and personally.

Learning Objectives

By the end of this section, students will be able to:

1. Define key nutrition concepts and describe how they relate to individual and public health.
2. Explain the significance of food quality and its impact on nutrient intake and overall well-being.
3. Identify major nutrient classes and describe their roles in the body.
4. Describe basic molecular concepts relevant to nutrition, including atoms, molecules, and chemical structures in food.
5. Distinguish between units of measure used in nutrition science (e.g., calories, grams, milligrams).
6. Interpret the relationship between nutrition and health risk factors using evidence-based frameworks.
7. Reflect on personal eating habits and attitudes toward food through a structured diet analysis activity to establish a foundation for self-awareness and future learning.

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1.1.1: Thinking About Food

What comes to mind when you think of food? What does it mean to you?

Maybe it is this morning's breakfast, essential fuel grabbed as you ran out the door to make it to work or class on time.

Or perhaps it's the smell of food cooking in your childhood kitchen, building anticipation for a meal to be shared with family.

Maybe it is the feeling of soil crumbling between your fingers as you prepare a garden bed for the first seeds of spring, each one a promise of fresh food for the months to come.

Or perhaps it is the thought of navigating your grocery cart down fluorescent-lit aisles at the grocery store, wondering what to choose and how to stay within your budget.

Maybe you think of food as a collection of nutrients, tiny molecules that will nourish and energize you, defend your health, and fuel your brain.

Or perhaps you think of the food traditions of your family's culture, recipes shared for generation upon generation, over decades of change.

Maybe you think primarily of feeding yourself. Or perhaps you're already planning what to cook for your large family tonight.

Maybe food is a collection of sweet memories for you. Or perhaps your relationship with food is more complicated, one of struggle and control.



Figure 1.1.1.1:
Photo by Tim Mossholder / Unsplash



Figure 1.1.1.2:
Photo by National Cancer Institute / Unsplash



Figure 1.1.1.3:
Photo by Franki Chamaki / Unsplash



Figure 1.1.1.4:
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Maybe the meaning of food is bigger than you and your family. Perhaps you think of how to best feed patients in a hospital, to nourish children in a school, or to get food to elderly shut-ins looking for a warm meal and a friendly face. Or maybe you think of how food production affects the environment, workers, and communities. Perhaps you wonder how we'll feed the world as the population grows and the climate warms.

Food is all of these things and more. It is a basic human need that permeates every day of our lives. The choices we make about food can affect something as small as the cells in our body and as large as the environment around us. We can't cover every facet of food in this book, but what we can do is give you a foundation on which to understand the science of food and nutrition and how to apply it in your everyday life.

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1.1.2: Food Quality

Good nutrition means eating the right foods, in the right amounts, to receive enough (but not too much) energy, fiber, and essential **nutrients** — chemical substances found in food that are required by the body to provide energy, give the body structure, and help regulate chemical processes — so that the body can remain free from disease, grow properly, work effectively, and feel its best. One measurement of food quality is the amount of nutrients it contains relative to the amount of energy it provides, known as **nutrient density**. High-quality foods are nutrient-dense, meaning they contain significant amounts of one or more essential nutrients relative to the amount of calories they provide. Nutrient-dense foods are the opposite of "empty-calorie" foods such as carbonated sugary soft drinks, which provide many calories and very little, if any, other nutrients. Food quality is additionally associated with its taste, texture, appearance, microbial content, and how much consumers like it.

Later in this book, additional considerations for achieving a healthy diet will be addressed — adequacy, variety, proportionality, moderation, and energy balance.



Figure 1.1.2.1: Image by David De Veroli on unsplash.com / CC0

Food: A Better Source of Nutrients

It is better to get your nutrients from the foods you eat than from dietary supplements. Dietary supplements — often in the form of pills — might contain what is listed on the label, but foods also contain macronutrients, micronutrients, and other beneficial components, such as phytochemicals found in plants, that benefit health. Dietary supplements, which include vitamin and mineral supplements, as well as herbal and botanical products, are a multi-billion industry in the United States and are not regulated by the FDA in the same way that prescription medications are regulated. Even though more than 50% of Americans report purchasing and using them daily, there is no consistent evidence that dietary supplements are better than food in promoting health and preventing disease.

Everyday Connection

Make a list of some of your favorite foods and visit the "FoodData Central" search tool provided by the USDA. What are some of the nutrients found in your favorite foods?

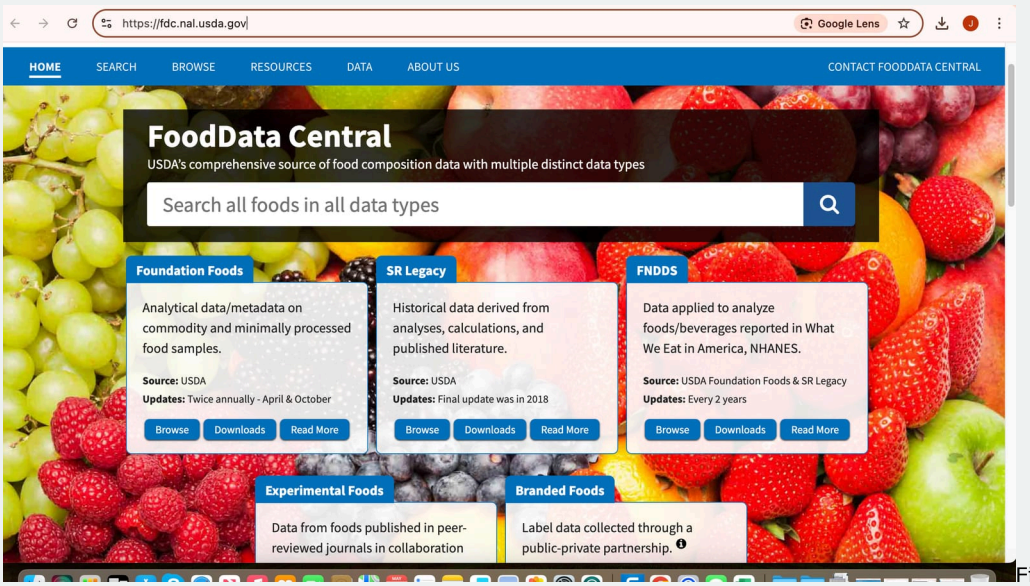


Figure 1.1.2.2: USDA

Query 1.1.2.1

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1.1.3: Nutrition and Health

Learning Objectives

- Explain the terms nutrition, health, health promotion, and disease prevention.

What is Nutrition?

Food is defined as any nutritious substance that people eat to maintain life and growth. **Nutrition** is how food affects the health of the body. According to the Academy of Nutrition and Dietetics, “Food is essential—it provides vital nutrients for survival, and helps the body function and stay healthy. Food is comprised of macronutrients including protein, carbohydrate and fat that not only offer calories to fuel the body and give it energy but play specific roles in maintaining health. Food also supplies micronutrients (vitamins and minerals) and phytochemicals that don’t provide calories but serve a variety of critical functions to ensure the body operates optimally.”[1] (**Phytochemicals** are compounds found in plants that give them their smell, taste, and color. They are not (yet!) considered essential nutrients, but many have been shown to affect human health.)



Figure 1.1.3.1: Photo by Dan Gold / Unsplash License

The **study of nutrition** goes beyond just a discussion of food and the nutrients needed by the body. It includes how those nutrients are digested, absorbed, and used by the cells of the body. It examines how food provides energy for daily activities and how our food intake and choices impact body weight and risk for chronic diseases such as heart disease and type 2 diabetes. It also provides insight on behavioral, social, and environmental factors that influence what, how, when, and why we eat.[2] Thus, nutrition is an important part of the overall discussion of health and wellness.

As you read about nutrition and health, you may see many references to the term "diet". In popular culture, this word is often associated with restrictive eating plans, food or beverage limitations, or rigid eating schedules. However, in the context of nutrition science, the term **diet** simply refers to the kinds of foods and beverages that someone eats or drinks. Scientists study different diets, patterns of eating, and lifestyle factors such as physical activity to learn more about the relationships between nutrition and health.

How Nutrition Affects Health

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."[3] The WHO recognizes nutrition as a critical part of health and development, noting that better nutrition is related to:[4]

- improved infant, child and maternal health
- stronger immune systems
- safer pregnancy and childbirth
- lower risk of non-communicable diseases (such as type 2 diabetes and cardiovascular disease)
- greater longevity
- greater productivity, creating opportunities to break cycles of poverty and hunger

Malnutrition is a condition that develops if someone does not consume enough nutrients, or if they have too much of certain nutrients, or if there is an imbalance or disorder in the ways that nutrients are utilized in the body. It can be caused by not having enough food to eat, not eating enough nutrient-rich foods, or having digestive problems or other health conditions. Malnutrition is a significant threat to human health. In fact, nutrition is relevant to six (6) of the top ten leading causes of death in the United States, including heart disease, cancer, stroke, diabetes, kidney disease, and liver disease.[5] Although a number of factors can contribute to the development of these diseases, poor nutrition can be a **primary, modifiable risk factor** or cause of each of these nutrition-relevant diseases. For example, specific dietary patterns with high sodium and low potassium intakes can contribute to hypertension, increasing risk for heart disease, stroke, and kidney disease. Diets high in processed meats are linked to colorectal cancer, while low intake of fruits and vegetables may reduce protective antioxidants that help prevent cell damage, leading to increased cancer risk. Alcohol consumption is linked to cancers of the liver, breast, colorectum, esophagus, head and neck. A diet high in saturated fats, refined sugars (especially fructose), and excess calories can contribute to the development of non-alcoholic fatty liver disease (NAFLD) by promoting insulin resistance and liver fat accumulation; over time, this can progress to metabolic dysfunction–associated steatotic liver disease (MASLD) and eventually to liver inflammation, fibrosis, and hepatocellular carcinoma (liver cancer). In total, these nutrition-relevant diseases account for approximately 70% of the leading causes of death in the United States — see Figure 1.3.2 below.

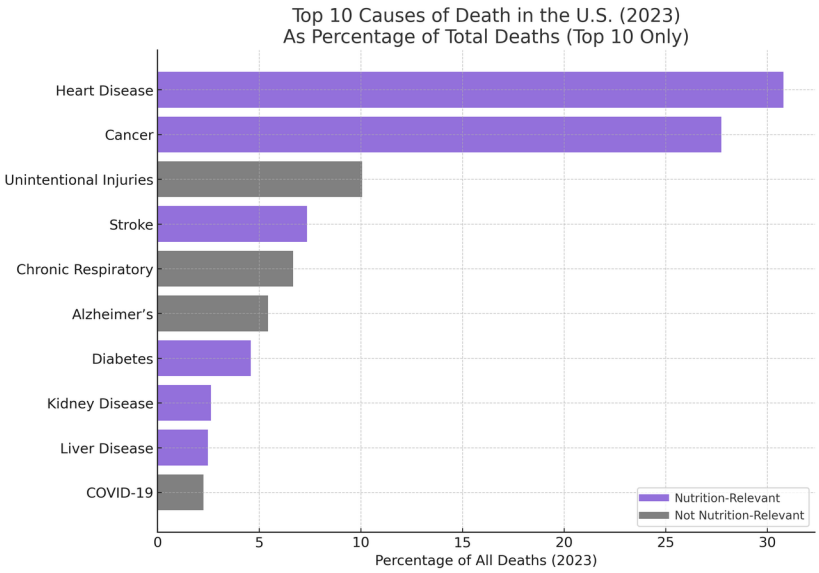


Figure 1.1.3.2: Top 10 Causes of Death in the United States as a Percentage of Total Deaths, 2023; Image generated by ChatGPT using data from "Mortality in the United States, 2023" by Centers for Disease Control and Prevention / Public Domain

Nutrition can affect the health of the mind as well as the body. For example, some research suggests that the foods people eat can influence their mood. A 2019 study of moderately-depressed people aged 17 to 35 years old found that when half of them shifted towards a Mediterranean-style eating pattern for 3 weeks—emphasizing more fruits and vegetables, whole grains, lean protein sources, unsweetened dairy, fish, nuts and seeds, olive oil, and spices—their depression levels decreased compared to participants who continued their usual eating habits. Some (but not all) other studies have also found links between healthier diets and decreased risk of depression. It's not clear why this might be, but researchers speculate that decreased inflammation

or changes in the body's microbiome caused by these dietary patterns may play a role in brain functioning and mental health.[6] This is an area that requires much more research, but as you're thinking about dietary choices, it's worth thinking about how foods make you feel.

In addition to nutrition, **health is affected by genetics, the environment, life cycle, and lifestyle**. One important facet of lifestyle is personal dietary habits. **Dietary habits** include what a person eats, how much a person eats during a meal, how frequently meals are consumed, and how often a person eats out. Other aspects of lifestyle include physical activity level, recreational drug use, and sleeping patterns, all of which play a role in health and impact food choices and nutrition status. Following a healthy lifestyle improves your overall health and well-being.



Figure 1.1.3.3: Photo by Thought Catalog / Unsplash License

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 of flour (adding vitamins and minerals), 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. The Dietary Guidelines for Americans[7], which are published every 5 years, aim to promote health and prevent chronic diseases. These guidelines outline ways to improve your overall eating patterns.

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1.1.4: An Introduction to Molecules

Learning Objectives

- Describe the basic structure of molecules.
- Identify elements found in the foods we eat.

In order to understand the chemical structure of nutrients and how they function in the body and provide energy to cells of the body, it is helpful first understand the basic chemical structure of molecules. ***Nutrients*** are chemical molecules that are found in foods and required by our bodies to maintain life and support growth and health. We focus on essential nutrients in this book, which are nutrients the body cannot make (synthesize) on its own to meet biological need — We have to get our nutrients from food. On this page, we'll zoom in to understand how atoms bond together to form these chemical molecules.



Figure 1.1.4.1: "Lemons and Vitamin C" by Heather Leonard, CC BY-NC 4.0, edited from photo by Lauren Mancke on Unsplash (license information) and "Ascorbic Acid" by Yikrazuul in the Public Domain.

The Atom

Matter is anything that has mass and takes up space. All living and nonliving things are composed of matter. ***Atoms*** are the fundamental unit of matter. The chair you are sitting in is made of atoms. The food you ate for lunch was built from atoms. Even the air you breathe is made of atoms. An atom is the smallest unit of an element, just like a blade is the smallest unit of grass. An ***element*** is made entirely from one specific type of atom. There are more than 100 elements that make up the world we live in, however hydrogen, carbon, nitrogen, and oxygen make up the bulk of all living things. Many elements are found in the foods we eat and all of them are found on the Periodic Table of Elements.

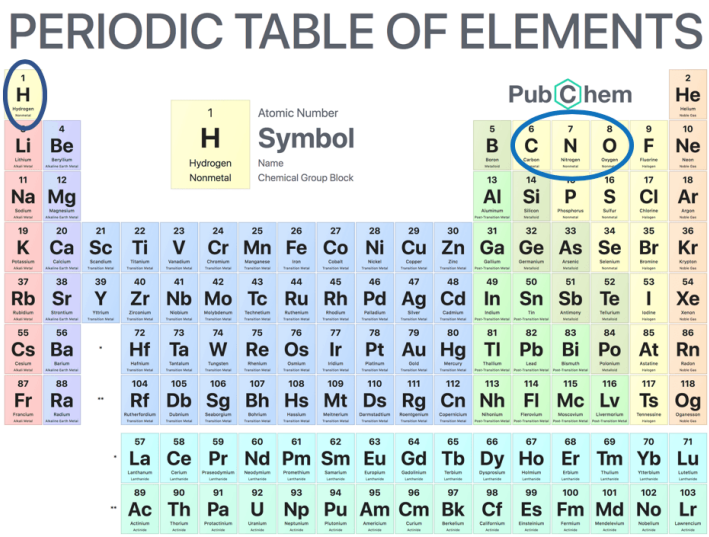


Figure 1.1.4.2: “Periodic Table of Elements” by Heather Leonard, CC BY-NC 4.0, edited from photo by “Periodic Table of Elements” by PubChem, U.S. National Library of Medicine is in the Public Domain

Atoms are unimaginably small. Even within a single microscopic cell, there is room for not just billions, but trillions or even hundreds of trillions of atoms. The atoms themselves are made of even smaller particles called ***protons***, ***neutrons***, and ***electrons***. Protons and neutrons are found in the nucleus (center) of the atom, while electrons are found outside the nucleus in regions called shells. Protons have a positive charge, neutrons have no charge, and electrons are negatively charged. Because protons and neutrons are contained in the dense nucleus of the atom, the nucleus has a positive charge. And since opposites attract, electrons are attracted to this nucleus and move around it in an electron cloud surrounding the nucleus. This attraction keeps the atom together, much like the force of gravity keeps the moon in orbit around Earth.

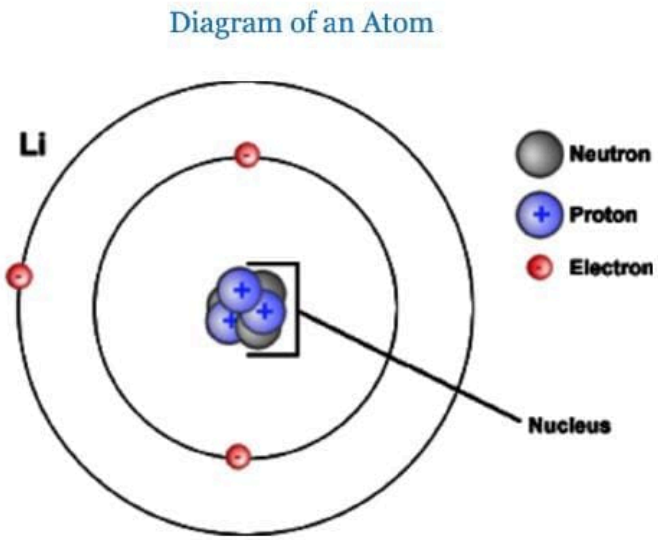


Figure 1.1.4.3: Diagram of a lithium atom, showing the placement of protons, neutrons, and electrons. Protons and neutrons are found in the nucleus (center) of the atom. Electrons are found outside the nucleus. “Diagram of an Atom” from “Introduction to Biology” by Open Learning Initiative is licensed under CC BY-NC-SA 4.0

Molecules and Covalent Bonding

Atoms combine to form a larger and more complex entity called a molecule. ***Molecules*** are composed of two or more atoms held together by chemical bonds.

The electrons of an atom contain energy. This energy is stored within the charge and movement of electrons and the bonds that atoms make with one another. However, this energy is not always stable, depending on the number of electrons within an atom. **Atoms are more stable when their electrons orbit in pairs.** An atom with an odd number of electrons must have an unpaired electron. In most cases, these unpaired electrons are used to create chemical bonds. A ***chemical bond*** is the attractive force between atoms and contains energy. By bonding, electrons find pairs, and atoms become part of a molecule.

The most stable situation for an atom is to have its outer shell completely filled with electrons. It is not easy to explain why this is true, but it's a rule of thumb that predicts how atoms will react with each other. **The first electron shell of an atom is considered full (or stable) when it contains two electrons, and the second and third shells are full (stable) with eight electrons.** Atoms tend to bond to other atoms in such a way that both atoms have filled outer shells as a result of the interaction. While some elements may be able to hold more electrons in their third shell, most of the important elements in biology (e.g. hydrogen, carbon, nitrogen, and oxygen) are considered stable with eight electrons in this outer shell.

Instead of transferring their electrons completely, atoms typically remain in very close contact and share electrons so that their outer shells are filled. In essence, a shared electron is counted "twice" and participates in a larger shell that joins the two atoms. A single pair of shared electrons makes a single covalent bond. Atoms can also share two pairs of electrons (in a double bond). This sharing of electrons is called a ***covalent bond***. Covalent bonds are the strongest, most stable types of chemical bonds in the biological world.

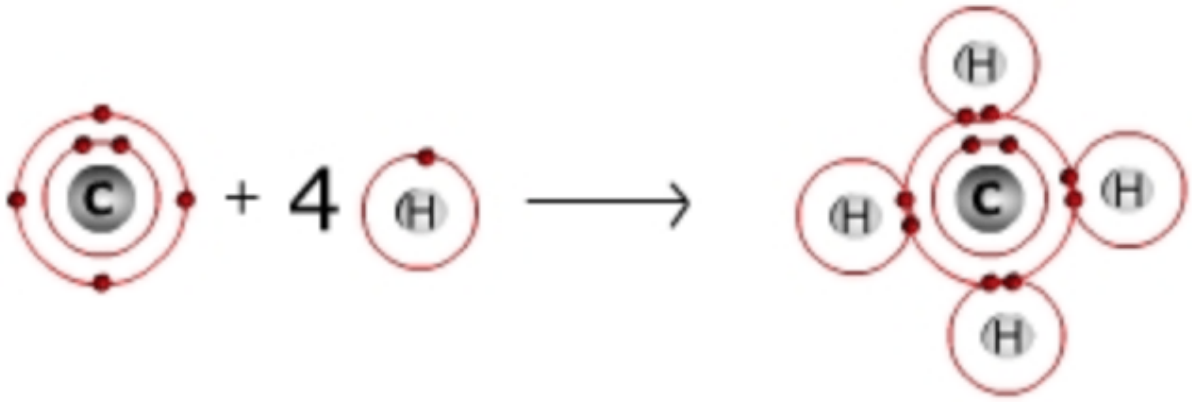


Figure 1.1.4.4: A molecule of methane. Carbon and hydrogen react to form methane by sharing electrons through a covalent bond. "Formation of Methane" from "Introduction to Biology" by Open Learning Initiative is licensed under CC BY-NC-SA 4.0

In food and in components of the human body, energy resides in the chemical bonds of specific molecules. Bond formation and bond breaking are chemical reactions that involve the movement of electrons between atoms. These chemical reactions occur continuously in the body. **When the chemical bonds of nutrients in the foods we eat are broken, energy is released.** That energy is used by cells of the body to perform daily functions and tasks such as breathing, walking up a flight of steps, and studying for a test.

YouTube Video

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Video 1.1.4.1: The science of macaroni salad: What's in a molecule? - Josh Kurz. Available at https://youtu.be/4WR0_gEEZ9I

Biological Macromolecules

As we noted earlier, atoms are the building blocks of all matter. ***Biological macromolecules*** are formed when atoms of carbon, hydrogen, oxygen, and nitrogen bond with each other in unique and varied ways. Biological macromolecules are the raw materials used to build living organisms. They are special molecules that contain carbon atoms covalently bonded with hydrogen atoms.



Figure 1.1.4.5: Tacos image by Constanze Riechert-Kurtze / Pixabay License

There are three classes of biological macromolecules (or **macronutrients**) that we will study in this course: carbohydrates, lipids, proteins. These macronutrients are probably already familiar to you, because they are some of the nutrients you ingest every time you eat. Water (also a macronutrient) and vitamins (a micronutrient) are also molecules, but much smaller in size and are absorbed intact. Minerals (another micronutrient) such as calcium, iron, and iodine are elements from the Periodic Table shown in Figure 1.4.2. By eating a variety of nutrient-dense foods in adequate quantities, you provide your cells with the building materials and energy necessary to sustain life. The next section will take a closer look at these important macronutrients and the role they play in our diet and in providing energy to cells.

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1.1.5: 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.

Food is one of life’s greatest pleasures. It offers amazing flavors, aromas, and textures. Food also provides our body with essential nutrients and non-nutrients like phytochemicals, both of which are vital to health. This section will discuss the six classes of nutrients and how these nutrients can be classified.

What are Nutrients?

Nutrients are chemical substances found in food that are required by the body to provide energy, give the body structure, and help regulate chemical processes. **There are six classes of nutrients:**

1. carbohydrates
2. lipids
3. proteins
4. water
5. vitamins
6. minerals

Nutrients can be further classified as either ***macronutrients*** or ***micronutrients*** and either ***organic*** or ***inorganic***, as well as whether or not they provide energy to the body (***energy-yielding***). We’ll discuss these different ways of classifying nutrients in the following sections.

Food is one of life’s greatest pleasures. It offers amazing flavors, aromas, and textures. Food also provides our body with essential nutrients and non-nutrients like phytochemicals, both of which are vital to health. This section will discuss the six classes of nutrients and how these nutrients can be classified.

Foods also contain non-nutrients, such as phytochemicals found in plants. Some non-nutrients appear to be very important for human health, like antioxidants; other naturally occurring non-nutrients can interfere with nutrient absorption, such as phytates, oxalates and tannins. Foods may also contain non-nutrients such as preservatives, colorings, flavorings and pesticide residues, some of which might be harmful to human health.

Table 1.1.5.1: Six Classes of Nutrients and Their Functions

Nutrient	Functions
Carbohydrates	Provide a ready source of energy for the body (sometimes referred to as the preferred source of energy for the body). Fiber, an indigestible carbohydrate to humans, is an important food source for gut microbes.
Lipids (Fats)	Provide stored energy for the body. Function as structural components of cells, hormones, and also as signaling molecules for proper cellular communication. Provide cushioning to vital organs and works to maintain body temperature through insulation.
Proteins	Necessary for tissue formation, cell repair, regulating fluid balance, and hormone and enzyme production. Essential for building strong muscles and a healthy immune system.

Nutrient	Functions
Water	Transports essential nutrients to all body parts, transports waste products for disposal, and aids with body temperature maintenance.
Vitamins	Regulate body processes and promote normal body-system functions. B-vitamins act primarily as co-enzymes in cellular respiration, helping convert macronutrients into energy. Vitamins C and E function as antioxidants, protecting cells from oxidative damage caused by free radicals. Additionally, vitamin D supports calcium absorption and bone health, vitamin A is essential for vision and immune function, and vitamin K plays a key role in blood clotting.
Minerals	Regulate body processes, are necessary for proper cellular function, and comprise body tissue. They play critical roles in nerve transmission, muscle contraction, fluid balance, and enzyme activity. For example, calcium, magnesium and phosphorus are critically important components of bones and teeth, iron is vital for oxygen transport in red blood cells, and sodium, potassium, and magnesium help maintain fluid balance and support nerve and muscle function.

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 through the process of cellular respiration to perform basic functions. The energy from these macronutrients comes from their chemical bonds. This chemical energy is converted through the process of cellular respiration into cellular energy in the form of ATP (adenosine tri-phosphate), which 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).

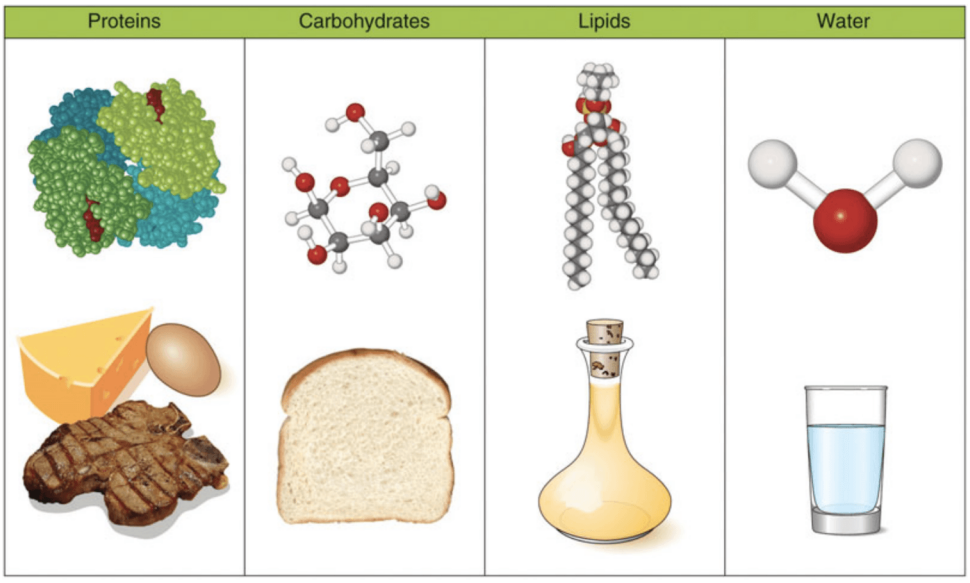


Figure 1.5. Macronutrients include proteins, carbohydrates, lipids, and water. This figure illustrates each nutrient's chemical structure and examples of food sources.

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 carbohydrate, 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.

Lipids (Fats)

Lipids (fats) are found predominately in butter, oils, meats, dairy products, nuts, seeds, olives, avocados and in 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. In addition to energy storage, lipids surround and protect organs, aid in temperature regulation, are used to make some hormones, and regulate many other functions in the body.

Proteins

Major food sources of proteins include meats, dairy products, seafood, eggs, and a variety of different plant-based foods (e.g., beans, nuts, and seeds). 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, are used to make some hormones, and play a role in conducting most of the chemical reactions that take place in the body.

Water

There is one other nutrient that we must have in large quantities: water. Water does not contain carbon, but is composed of two hydrogen atoms and one oxygen atom per molecule of water. 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.

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 (Tables 1.1.5.2 and 1.1.5.3 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 iron is a necessary component of red blood cells to transport oxygen effectively — without adequate iron intake, one can develop iron-deficiency anemia, which leads to a sense of low-energy and feeling tired. Additionally, many B vitamins (e.g., thiamin, riboflavin, & niacin) 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.

Vitamins

The thirteen vitamins are categorized as either water-soluble or fat-soluble. The water-soluble vitamins are vitamin C and all the B vitamins, which include thiamin, riboflavin, niacin, pantothenic acid, pyroxidine, biotin, folate and cobalamin. Choline is also included here, even though it is not classified as a vitamin because it can be synthesized by the body. However, the synthesis of choline is limited and therefore choline is recognized as an essential nutrient.

The fat-soluble vitamins are A, D, E, and K. Vitamins are required to perform many functions in the body such as facilitating the chemical reactions that yield energy, making red blood cells, synthesizing bone tissue, and playing a role in normal vision, nervous system function, and immune system function.

Table 1.1.5.2: Vitamins and Their Major Functions

Vitamins	Major Functions
Water-soluble	
B_1 (thiamin)	Coenzyme, energy metabolism assistance
B_2 (riboflavin)	Coenzyme, energy metabolism assistance
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
Choline	Cell membrane structure, neurotransmitter synthesis, lipid metabolism, and methylation
Fat-soluble	
A	Vision, reproduction, immune system function
D	Bone and teeth health maintenance, immune system function
E	Antioxidant, cell membrane protection
K	Bone and teeth health maintenance, blood clotting

The following video provides a nice overview of vitamins:

YouTube Video

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Video 1.1.5.1: How do vitamins work? - Ginnie Trinh Nguyen. Available at https://youtu.be/ISZLTJH5lYg

Minerals

Minerals are solid inorganic substances that form crystals and are classified depending on how much of them we need. Trace minerals such as molybdenum, selenium, zinc, iron, and iodine, are only required in only a few milligrams or less, whereas major minerals, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in hundreds of milligrams each day. Many minerals are critical for enzyme function, others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals.

Table 1.1.5.3: : Minerals and Their Major Functions

Minerals	Major Functions
Major	
Sodium	Fluid balance, nerve transmission, muscle contraction
Chloride	Fluid balance, stomach acid production
Potassium	Fluid balance, nerve transmission, muscle contraction
Calcium	Bone and teeth health maintenance, nerve transmission, muscle contraction, blood clotting
Phosphorus	Bone and teeth health maintenance, acid-base balance
Magnesium	Protein production, nerve transmission, muscle contraction
Sulfur	Protein production
Trace	
Iron	Carries oxygen, assists in energy production
Zinc	Protein and DNA production, wound healing, growth, immune system function
Iodine	Thyroid hormone production, growth, metabolism

Minerals	Major Functions
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 compromised immune function and night blindness. Anemia, a condition where there aren't enough healthy red blood cells to carry adequate oxygen throughout the body, can result from deficiencies in iron or in vitamins B6, folate, and B12.

Energy-Yielding Nutrients

The macronutrients—carbohydrate, protein, and fat—are the only nutrients that provide energy to the body. The energy from macronutrients comes from their chemical bonds. This chemical energy is converted into cellular energy that can be utilized to perform work, allowing cells to conduct their basic functions. **Although vitamins also have energy in their chemical bonds, our bodies do not make the enzymes to break these bonds and release this energy.** (This is fortunate, as we need vitamins for their specific functions, and breaking them down to use for energy would be a waste.)

Food energy is measured in kilocalories (kcals). A kilocalorie is the amount of energy needed to raise 1 kilogram of water by 1 degree Celsius. The kilocalories stored in food can be determined by putting the food into a bomb calorimeter and measuring the energy output (energy = heat produced).

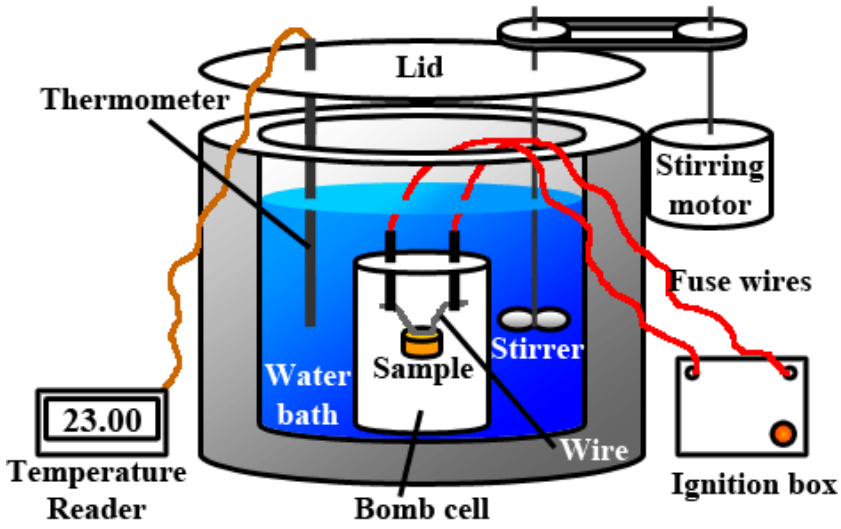


Figure 1.6. A Bomb calorimeter

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VIDEO: "Bomb Calorimetry" by David Read, YouTube (September 16, 2008), 2:19 minutes.

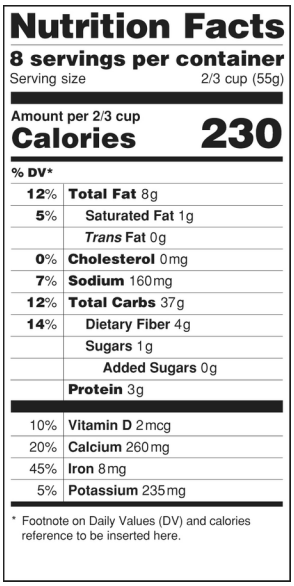
In the US, the kilocalorie (kcal) is the most commonly used unit of energy and is often just referred to as a Calorie. Strictly speaking, a kcal is 1000 calories. In nutrition, and in this textbook, the term Calories almost always refers to kcals. Sometimes the kcal is indicated by capitalizing calories as "Calories." For the sake of simplicity, we'll use the terms "calories" and "kilocalories" interchangeably in this book.

Below is a list of energy sources in the diet from lowest to highest calories per gram (a gram is about the weight of a paperclip). Notice the inclusion of alcohol. Although alcohol does provide energy, it is not considered a nutrient, because it is not essential to life and is increasingly viewed as being harmful to human health.

Energy Sources (kcal/g)

- Carbohydrates 4
- Protein 4
- Alcohol 7
- Lipids 9

Carbohydrates and proteins provide 4 calories per gram, and fats provide 9 calories per gram. Fat is the most energy-dense nutrient, because it provides the most calories per gram (more than double carbohydrates and protein).



Nutrition Facts

8 servings per container

Serving size 2/3 cup (55g)

Amount per 2/3 cup

Calories 230

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

* Footnote on Daily Values (DV) and calories reference to be inserted here.

Figure 1.1.5.1: "FDA Nutrition Facts Label" by USDA Food and Drug Administration is in the Public Domain

Example 1.1.5.1: How to calculate the energy available from foods

When you look at the Nutrition Facts panel on a food label, you'll see that it lists calories, as well as grams of total fat, total carbohydrates, and protein per serving. From these values, you can estimate the amount of calories coming from the different macronutrients.

Looking at the values in the Nutrition Facts label, you can convert grams into calories by doing the following calculations:

- 8 grams of fat x 9 kcal/g = 72 kcals
- 37 grams of carbohydrate x 4 kcal/g = 148 kcals
- 3 grams of protein x 4 kcal/g = 12 kcals

You can double check your math by adding the calories per serving provided from fat, carbohydrate, and protein. This number should come close to the total calories per serving listed on the Nutrition Facts. It will not always match up exactly (like in this example) due to rounding.

- 72 kcals from fat + 148 kcals from carbohydrate + 12 kcals from protein = 232 kcals total

Example 1.1.5.2: How to calculate the percentage of the total energy provided by one nutrient

Using the information listed in the previous example, you can calculate the percentage of the total kcalories that are provided by each of the nutrients in the food: carbohydrate, protein, and fat. For example, to find the percentage of kcalories from fat in the food, divide the kcals from fat by the total kcalories. You can round this number to two decimal places for simplicity.

- 72 kcals from fat / 232 kcals total = 0.31

Next, multiply by 100 to find the percentage.

- 0.31 x 100 = 31%

In this example, 31% of the total calories in the food were contributed by fat. Dietary recommendations suggest that 20 to 35% of your daily calories come from fat, 10 to 35% from protein, and 45 to 65% from carbohydrates.[1] These recommendations refer to the total energy intake for each day, not from individual foods. However, it can be useful to understand the contribution that each nutrient makes as you consider food choices for a well-balanced diet.

YouTube Video

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Video 1.1.5.2: What is a calorie? - Emma Bryce. Available at https://youtu.be/VEQaH4LruUo

Organic and Inorganic Nutrients

So far, we've categorized nutrients as macronutrients or micronutrients and based on whether or not they're energy-yielding. There is one more way to categorize nutrients: organic or inorganic. When you think of the word "organic," you might think of how foods are produced (with or without synthetic fertilizers and pesticides), but in this case we are referring to the chemical structure of a nutrient.

Organic Nutrients

The organic nutrients include the macronutrients (carbohydrate, protein, and fat) and vitamins. An organic nutrient contains both carbon and hydrogen. Organic nutrients can be made by living organisms and are complex, made up of many elements (carbon, hydrogen, oxygen, and sometimes nitrogen) bonded together. In a sense, they are "alive," and therefore can be destroyed or broken down.

Vitamin E (shown below) is an organic molecule, because it contains both carbon and hydrogen atoms. Vitamin E is synthesized by plants and can be destroyed by heat during cooking.

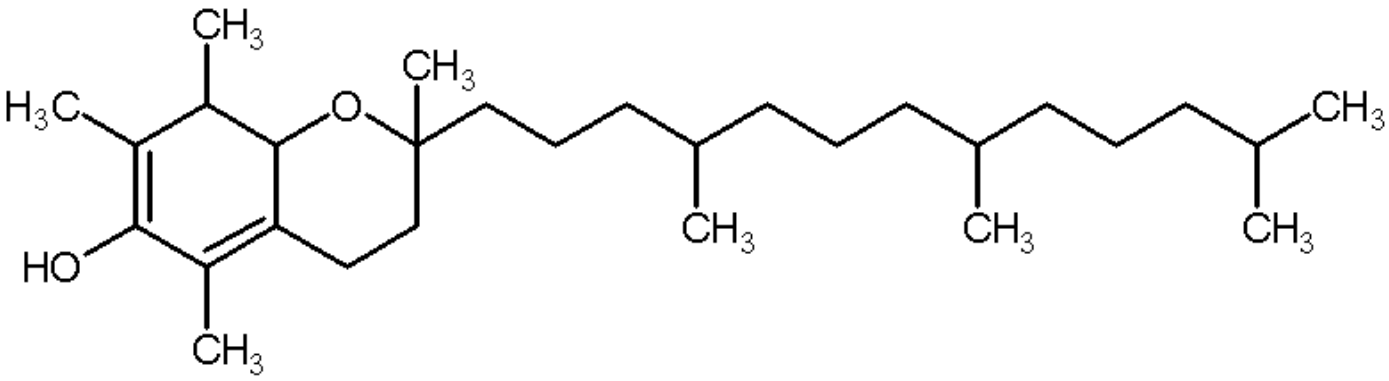


Figure 1.1.5.2: “Vitamin E” by Annabel is licensed under CC BY-SA 3.0

Inorganic Nutrients

Inorganic nutrients include both water and minerals. Inorganic nutrients do not contain both carbon and hydrogen, and they are not created or destroyed. Minerals can’t be destroyed, so they are the ash left when a food is burned to completion. Minerals are also not digested or broken down, as they are already in their simplest form. They are absorbed as-is, then shuttled around the body for their different functions, and then excreted.

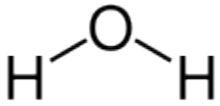


Figure 1.1.5.3: "Skeletal Structure of Water" by TSOL is licensed under CC BY-SA 4.0

Summary

The different categories of nutrients are summarized in the following table.

Table 1.1.5.4: “Summary of classification of nutrients” by Tamberly Powell is licensed under CC BY-NC-SA 4.0

Classification	**Nutrient**
Macronutrient	Carbohydrate, protein, lipids, water
Micronutrient	Vitamins, minerals
Energy-Yielding	Carbohydrate, protein, fat
Organic	Carbohydrate, protein, lipids, vitamins
Inorganic	Minerals, water

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.

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References

1. Food and Nutrition Board of the Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. (Washington, DC: National Academies Press, 2005).

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1.1.6: Units of Measure

Learning Objectives

- Compare and contrast the Metric and US Customary systems of measurement.

In nutrition, there are two systems of commonly used measurements: Metric and US Customary. The US Customary system is more commonly used among the public in the United States. For example, many people refer to body weight in pounds, rather than in kilograms. However, the Metric system is more commonly used in science. It is good to become familiar with both measurements, and to learn how to convert between them. In the United States, the energy content of food is expressed in Calories (kcal), whereas in science and in many countries, energy in food is expressed using the SI Unit, Joules (J) or Kilojoules (kJ).

The Metric and US Customary System

These are commonly used prefixes for the Metric System:

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

Energy

SI (International System of Units)	US Customary System	Conversions
Joule (J)	calorie (cal)	1 cal = 4.184 J
Kilojoule (kJ)	Calorie (kcal) — used to express the energy content of food. A food Calorie (kcal) = 1000 calories.	1 kcal = 4184 J or 4.184 kJ

Mass

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

Volume

Metric System	US Customary System	Conversions
Milliliter (mL)	Teaspoon (tsp)	1 tsp = 5 mL

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

Length

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

YouTube Video

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Video 1.1.6.1: Math Antics - Intro to the Metric System. Available at https://youtu.be/ZNX-a-5jGeM



Figure 1.1.6.1:
One 8-ounce cup of liquid
is about 240 milliliters.
One cup of orange juice
by Bruno /Germany / Pixabay

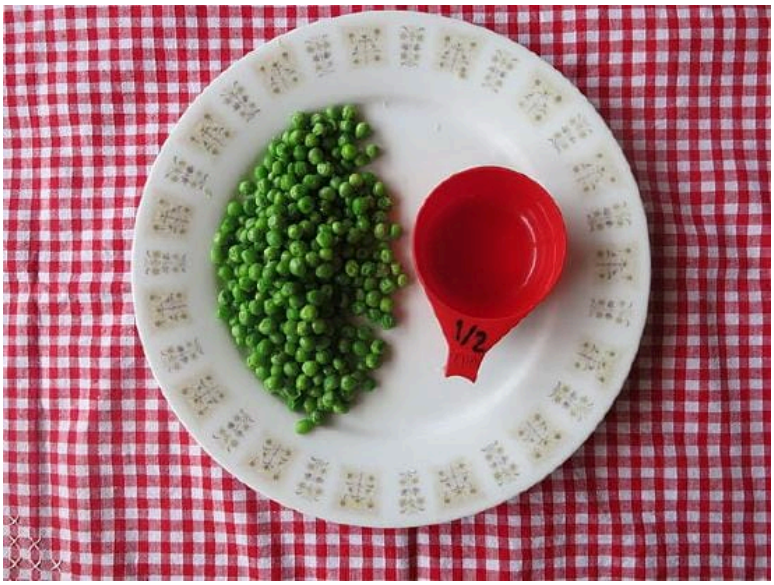


Figure 1.1.6.2:
A half cup of vegetables weighs about 75-100 grams, depending on the type and how it is prepared.
Half cup of peas by Hannahdownes / CC BY-SA 4.0



Figure 1.1.6.3:
A teaspoon of sugar weighs 4 grams.
Cinnamon Sugar by Ulrike Leone / Pixabay

Example 1.1.6.1: How to convert customary measurements to metric

- Weight in pounds converted to kilograms: divide the weight in pounds by 2.2
  Example: 150 pounds / 2.2 = 68 kilograms (rounded to the nearest whole number)
- Height in inches converted to meters: divide the height in inches by 39.37
  Example: 67 inches / 39.37 = 1.70 meters (rounded)
- Fluid volume in ounces converted to milliliters: multiply the volume in ounces by 30
  Example: 8 ounces x 30 = 240 milliliters

- Weight in ounces converted to grams: multiply the weight in ounces by 28.35
  Example: 12 ounces x 28.35 = 340 grams (rounded)

Attributions

- Human Nutrition: 2020 Edition, University of Hawai'i at Mānoa Food Science and Human Nutrition Program, "Units of Measure," CC BY-NC 4.0

Query 1.1.6.1

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1.1.7: Research Highlight - Risk Factors

Learning Objectives

Review and critically evaluate a scholarly, peer-reviewed, primary research publication.

*Note: Each chapter of Introduction to Nutrition Science includes a Research Highlight like this one. The purpose of each of these is to extend your knowledge of the chapter content to relevant research. A primary research publication is one in which the results of the author's research contribute new knowledge to the field of study.

Introduction

A **risk factor** is something that increases a person's chances of developing a disease. Nutrition researchers gather data and investigate the relationships between specific foods or dietary patterns and diseases like heart disease, cancer, and diabetes. The results can help people to make good choices about food and lifestyle to reduce their risk of developing a disease. Let's explore how that data is put to use to determine a dietary risk factor, such as not eating enough vegetables or eating too much sodium. As you read the publication linked below, consider the following questions:

1. What are your initial thoughts regarding the aim of this publication?
2. What is the question that the author is trying to answer with this publication?
3. What methods did the author use to determine an answer to the question?
4. What sorts of results did the author obtain, and how were those results analyzed?
5. What types of references does the author use to support the publication?
6. Do you agree with the conclusions to which the author came regarding an answer to the question?

Primary Publication

Fulgoni, V. L., 3rd, Wallace, T. C., Stylianou, K. S., & Jolliet, O. (2018). Calculating Intake of Dietary Risk Components Used in the Global Burden of Disease Studies from the What We Eat in America/National Health and Nutrition Examination Surveys. *Nutrients*, *10*(10), 1441. DOI: https://doi.org/10.3390/nu10101441

Further evaluation

To evaluate this publication further, it might help to know a little more about how "'risk" is determined. To begin, let's define the terminology. In **epidemiology**, which is the study of disease in specific populations, relative risk is a number between 1-100 that indicates one's relative risk of developing a disease. This is similar to a hazard ratio, which is essentially the same thing described as a ratio, rather than a percentage. In other words, a hazard ratio of 1.25 would indicate a relative risk of 125%.

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1. BMJ Publishing Group (2020). How to calculate risk. BMJ Best Practice. https://bestpractice.bmj.com/info/us...alculate-risk/

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1.1.8: Diet Analysis Activity - Foundations for Self Reflection

Learning Objectives

- Consider questions for exploring and assessing personal dietary intake.

Why are we doing this?

The Diet Analysis Activities in this textbook will give you the opportunity to take what you are learning about Nutrition Science and apply it in your own life. They will lead you to discover important details about the foods and beverages you consume, and encourage you to consider the impact of your nutrition choices on your personal health.

There are four key **Learning Objectives** that these activities are designed to help you achieve. These show what you should know, or be able to do, when you complete all of the Diet Analysis Activities. You should be able to:

1. evaluate the nutrient composition of foods and beverages.
2. compare personal dietary intake and physical activity with current recommendations.
3. develop meal and activity plans that meet nutritional needs.
4. choose nutrient-dense foods and beverages in appropriate amounts to promote health and reduce disease risk.

The main point: when we understand the importance of nutrition and healthful lifestyles, and when we know what types and amounts of nutrients our bodies need, we can make choices that help us to achieve and maintain good health. **Living well begins with eating well.**

These activities are meant to provide basic information and encourage exploration, not dictate specific diets or substitute for professional medical advice. Please keep your own medical and dietary situation in mind, and seek assistance from a qualified healthcare professional such as a Registered Dietitian Nutritionist or a Doctor of Medicine to address your specific needs.

Diet and health are often challenging subjects to discuss, for many reasons. Family and cultural background, personal experiences, social influences, and individual beliefs can all contribute to these challenges. If you have concerns about evaluating your own diet, weight, activity patterns, and health status, please talk to your instructor and/or a qualified healthcare professional. Assignments may be modified or alternate assignments may be available to help you meet these learning objectives without focusing on your own personal health.

Foundations for Self-Reflection

The first step in dietary assessment is to observe and collect information. Start by thinking about basic questions like the ones listed below. Try to remain objective, and avoid assigning value to specific foods and dietary patterns, such as "good" or "bad", "high" or "low". Simply notice the types of foods and beverages you choose on a typical day. Think like a scientist looking for evidence, or a detective gathering clues.

1. On a typical day, when do you first take a drink or eat a bite of food?
2. What types of beverages do you drink?
3. Where do you eat meals or snacks?
4. Do you enjoy flavors that are salty, spicy, sweet, tart, or savory?
5. Are your foods colorful? What colors are the foods you eat most often?
6. Do you usually eat alone or with other people?
7. What temperatures are the foods and beverages you consume?
8. How do you feel about various textures of foods, such as crunchy or chewy?
9. Did you notice the appearance and aroma of a food before you took a bite?
10. How did your body feel before eating a meal, compared to after you finished eating?

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1.2: IDENTIFYING WITH FOOD

This section explores the personal, psychological, and cultural dimensions of nutrition by examining how individuals identify with food and make dietary choices. Students will consider what it means to develop a healthy relationship with food, assess the concept of energy balance, and analyze different diet models through a critical, evidence-based lens. The unit also addresses body respect, and inclusive nutrition frameworks such as Health At Every Size® and intuitive eating. Using Maslow's Hierarchy of Needs and self-reflective tools, students will evaluate their own food behaviors in context, deepening their understanding of the complex factors that influence eating patterns and nutritional well-being.

Learning Objectives

By the end of this section, students will be able to:

1. Describe what constitutes a healthy and balanced philosophy toward food and eating.
2. Analyze behavioral, psychological, and cultural influences on food choices and eating patterns.
3. Explain the concept of energy balance and how it relates to metabolism, physical activity, and weight regulation.
4. Compare common dietary patterns and evaluate their health claims, nutritional adequacy, and cultural relevance.
5. Explain the principles of Health At Every Size® and intuitive eating as inclusive, weight-neutral approaches to health.
6. Apply Maslow's Hierarchy of Needs to understand the broader context of food behaviors and nutrition-related decision-making.
7. Reflect on personal eating responses and attitudes using a structured diet analysis activity to support critical self-awareness and informed dietary choices.

1.2.1: A Healthy Philosophy Toward Food
1.2.2: Eating Behaviors and Food Choices
1.2.3: Energy Balance — Calories In Versus Calories Out
1.2.4: Comparing Diets
1.2.5: Health At Every Size® and Intuitive Eating
1.2.6: Research Highlight - Maslow's Hierarchy of Needs
1.2.7: Diet Analysis Activity - Evaluating Food Responses

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1.2.1: A Healthy Philosophy Toward Food

Learning Objectives

- Explain why nutrition is important to health.
- Describe "undernutrition" and "overnutrition" and what leads to each.

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

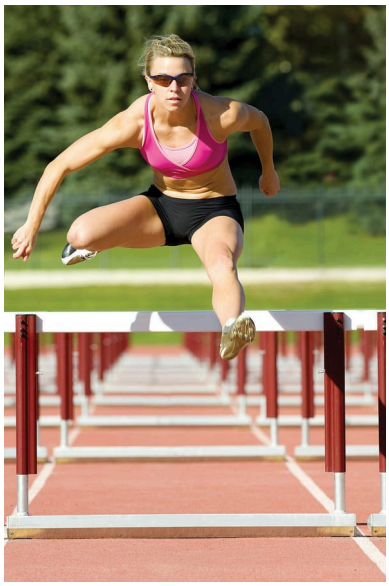


Figure 1.2.1.1: Nutrition provides the body with the nutrients it needs to perform all activities, from taking a breath to strenuous athletic activity. © Dreamstime

Good nutrition equates to receiving enough (but not too much) of the macronutrients (proteins, carbohydrates, fats, and water) and micronutrients (vitamins and minerals) so that the body can stay healthy, grow properly, and work effectively. Eating foods, ideally in their whole or minimally processed form, fuels the body by providing what it needs to produce energy, promote metabolic activity, prevent micronutrient deficiencies, ward off chronic disease, and to promote a sense of overall health and well-being.

Table 1.2.1.1: How Nutrients are Important to Health

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

Malnutrition — Undernutrition, Obesity and the 'Double Burden'

For many, the word “malnutrition” produces an image of a child in a low-income country with a bloated belly, and skinny arms and legs. However, this image alone is not an accurate representation of the state of malnutrition. For example, someone who is 150 pounds overweight can also be malnourished. **Malnutrition** refers to one not receiving good nutrition and does not distinguish between the consequences of too many nutrients or the lack of nutrients, both of which impair overall health. **Undernutrition** is characterized by a inadequate intake of nutrients or insufficient energy supply, whereas **overnutrition** is characterized by excessive nutrient or energy intake. Consuming more energy than needed can result in an energy imbalance and accumulation of excess body fat, which can lead to **obesity**.

Being malnourished with obesity or undernutrition is not just an either-or condition; it can involve both at the same time. The **double burden of malnutrition** refers to the coexistence of obesity and nutrient deficiencies, where a person might consume excess Calories yet still have inadequate intake of essential nutrients like iron, calcium, and vitamin D due to a diet high in energy-dense foods that are low in essential nutrients. The double burden can occur in countries, communities, families and even in individuals. For example, an individual with obesity can still have iron-deficiency anemia and an inadequate intake of vitamin D.

Although not as prevalent in the United States as it is in low-income countries, inadequate intake of essential nutrients is not uncommon and affects many sub-populations, including older adults, those with restrictive diets, certain diseases, and those in poverty. Many people who live with diseases either have no appetite or may not be able to digest food properly. Some medical causes of malnutrition include cancer, inflammatory bowel syndrome, AIDS, Alzheimer’s disease, illnesses or conditions that cause chronic pain, psychiatric illnesses, such as anorexia nervosa, or as a result of side effects from medications.

Obesity is an epidemic in the United States — According to the latest CDC data based on measured (not self-reported) height and weight from the National Health and Nutrition Examination Survey (NHANES) covering August 2021 to August 2023, the prevalence of obesity among U.S. adults is 40.3%. Obesity is known to be associated with many diseases, including Type 2 diabetes, cardiovascular disease, inflammatory disorders (such as rheumatoid arthritis), obstructive sleep apnea, and cancer.

Growth and Development

From birth to adulthood, nutrients fuel proper growth and function of all body cells, tissue, and systems. Without adequate amounts of nutrients, growth and development are stunted. Some nutrient deficiencies manifest right away, but sometimes the effects of undernutrition aren’t seen until later in life. For example, if children do not consume adequate calcium and vitamin D, peak bone mass will be reduced compared to what it would be had adequate amounts of these nutrients been consumed. When adults enter older age without adequate bone mass, they are more susceptible to osteoporosis, putting them at risk for bone fractures. Therefore, it is vital to build bone strength through proper nutrition during youth and before age 30 y because it cannot be done in later life. (1)



Figure 1.2.1.2: Optimal growth throughout the life stages depends upon good nutrition. © Dreamstime

The Healing Process

With all wounds, from a paper cut to major surgery, the body must heal itself. Healing is facilitated through adequate nutrition(2), while malnutrition inhibits and complicates this vital process. The following nutrients are important for proper healing:



Figure 1.2.1.3: Healing, a critical function of a healthy body, is facilitated by adequate nutrition.

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

You will learn more about these later in the text.

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

Key Takeaways

- Nutrition promotes vitality and an overall sense of health and well-being by providing the body with energy and nutrients that fuel growth, healing, and all body systems and functions. Good nutrition will also help to ward off the development of chronic disease.
- A person is malnourished by being either undernourished or overnourished, or both. Malnutrition results when the body does not receive the right amounts of calories, fats, proteins, carbohydrates, vitamins, and minerals necessary to keep the body and its systems in good functioning order.

Discussion Starter

1. Describe what the phrase, “You are what you eat” means. Do you notice how you feel after eating certain types of foods? How might this relate to your overall health?

Learning Check 1.2.1.1

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1.2.2: Eating Behaviors and Food Choices

Learning Objectives

Define the major influences that affect how people make food decisions.

Exploring Why and How We Eat

Eating is not just about nutrition and fueling our bodies, though that is a big part of it. Eating is cultural, pleasurable, and social.

How we eat is largely determined by how we are trained to eat growing up (though we can change our habits later). For instance, if the people we ate with as a child practiced restrictive dietary practices, we are more likely to do this or develop disordered eating behaviors. If the people we ate with as a child ate only pre-packaged ready-to-eat meals, we are more likely to eat packaged food and not learn to cook with fresh ingredients (or it can spur an interest in cooking!).

Changing behaviors as an adult can be difficult, but not impossible. Knowledge of nutrition and dietary guidelines might influence the food choices a person makes, but there are a number of other factors that affect the dietary choices individuals make.

Factors that Influence Food Choices

Why do people eat what they eat? Our food choices are influenced by personal factors, such as our taste preferences, our emotional states, and how hungry we are. More than just the product of willpower and personal responsibility, food choices are also shaped by income, culture, marketing, food availability, food policy, and a host of other factors, many of which lie outside of individual control. https://foodsystemprimer.org/food-and-nutrition

- **The Food Environment**
  The people in our social circles, such as our friends and family; our physical surroundings, including the stores in our communities, the foods they sell, and how much they cost; and other, more indirect influences, such as our exposure to advertising and the government policies that shape the food system. https://foodsystemprimer.org/food-nu...d-environments

- **Taste, texture, and appearance**
  Individuals have a wide range of tastes which influence their food choices, leading some to dislike milk and others to hate raw vegetables. Some foods that are very healthy, such as tofu, may be unappealing at first to many people. However, creative cooks can adapt healthy foods to meet most people's taste.
- **Economics**
  Access to fresh fruits and vegetables may be scant, particularly for those who live in economically disadvantaged or remote areas, where cheaper food options are limited to convenience stores and fast food.
- **Early food experiences**
  People who were not exposed to different foods as children, or who were forced to swallow every last bite of overcooked vegetables, may make limited food choices as adults.
- **Habits**
  It's common to establish eating routines, which can work both for and against optimal health. Habitually grabbing a fast food sandwich for breakfast can seem convenient, but might not offer substantial nutrition. Yet getting in the habit of drinking an ample amount of water each day can yield multiple benefits.
- **Culture**
  The culture in which one grows up affects how one sees food in daily life and on special occasions.
- **Geography**
  Where a person lives influences food choices. For instance, people who live in Midwestern US states have less access to seafood than those living along the coasts.
- **Advertising**
  The media greatly influences food choice by persuading consumers to eat certain foods.
- **Social factors**
  Any school lunchroom observer can testify to the impact of peer pressure on eating habits, and this influence lasts through

adulthood. People make food choices based on how they see others and want others to see them. For example, individuals who are surrounded by others who consume fast food are more likely to do the same.

- **Health concerns**
  Some people have significant food allergies, to peanuts for example, and need to avoid those foods. Others may have developed health issues, such as heart disease, that require them to follow a low salt diet.
- **Emotions**
  There is a wide range in how emotional issues affect eating habits. When faced with a great deal of stress, some people tend to overeat, while others find it hard to eat at all.
- **Green food/Sustainability choices**
  Based on a growing understanding of diet as a public and personal issue, more and more people are starting to make food choices based on their environmental impact. Realizing that their food choices help shape the world, many individuals are opting for a vegetarian diet, or, if they do eat animal products, striving to find the most "cruelty-free" options possible. Purchasing local and organic food products and items grown through sustainable processes also helps shrink the size of one's dietary footprint.

Discussion Starter:

What are some of the factors that influence the way you eat? Can you name specifics?

Learning Check 1.2.2.1

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1.2.3: Energy Balance — Calories In Versus Calories Out

Learning Objectives

Discuss the principles that complicate correlating body weight to human health.

Describe the negative health impacts of weight loss dieting and weight cycling.

The ability to estimate energy expenditure and quantify calories consumed, has led to the simple conclusion that tracking or counting “calories in” compared to “calories out” will result in an easy way to manage body weight. This logic does not take into account the complexity and individuality of the human body. Human bodies are not static, meaning there are fluctuations from day to day in energy needs related to set point, sleep patterns, stress levels, activity levels, and eating patterns. For example, something as simple as the timing and macronutrient composition of meals, will impact the thermic effect of food, resulting in a change in energy expenditure.



Figure 1.2.3.1: Image by mojzagrebinfo / Pixabay License

Dieting Basics/ Dieting 101

The diet and weight loss industry is big business. In 2017, The U.S. Weight Loss and Diet Control Market reported a record $72 billion dollar value to the weight loss market.[1] This dollar amount is expected to continue to rise. At the same time, there is evidence that the practice of dieting does not lead to long-term weight loss for the majority of people. In observational studies, dieting was the best predictor of future weight gain and onset of obesity.[2][3][4] Meta-analysis and reviews of randomized clinical trials before the use of GLP-1 medications reported that on average, obesity treatments cause weight gain.[5][6] This additional weight gain leads to an increase in the set point, making it more difficult for an individual to lose weight in the future. Others reported a 3-5 % weight loss was possible 4 years later if participants continued all aspects of treatment.[7] For a 200 pound person, this represents a 6-10 pound weight loss. The health benefits of this modest weight loss are unclear and it is far less than what is expected or desired when following a diet. In conclusion, the diet industry makes money by selling approaches that do not work for most people.

Dieting and Health

The scientific evidence shows that diets lead to modest weight loss for some and future weight gain for the majority of people.

This often leads to a behavior called weight cycling or yo-yo dieting. The person continues to seek weight loss and a new diet, hoping to get a new result. This repetition of starting and stopping diets leads to losing and gaining a similar amount of weight over and over again. The weight goes up and down like a yo-yo. Yo-yo weight cycling is more harmful to health than being overweight at a stable weight. In addition, when someone cuts out food groups and restricts certain foods from their diet, the interest in the food increases. This in combination with intense hunger resulting from energy restriction, leads to a feeling of being out of control around foods and binge eating. To compensate for the feeling out of control, the person then restricts the food again and is then in a restriction/binge or overeating cycle. [27]

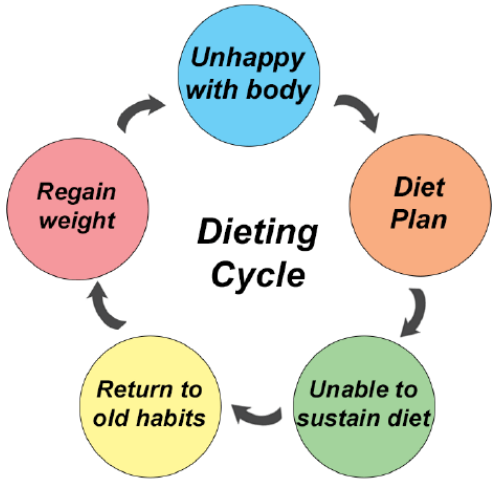


Figure 1.2.3.2: Image by Kellie Taguchi / CC BY 4.0

The majority (up to 95%) of people regain the weight within three years and often gain back more.[8][9] Weight cycling puts stress on the body causing physical complications that are harmful, resulting in lowered or slowed metabolism, a reduction in lean body mass or muscle tissue, lowered body temperature, and increased risk for eating disorders.[10][11] Dieting and weight cycling also have a negative impact on mental health including lower self-esteem, and increases in depression, anxiety, irritability, and nervousness.[12] The evidence shows that dieting reduces both physical and emotional health.

Health and Body Weight

The assumption that health is determined by body weight, or a number on the scale, is outdated and not supported by science. As obesity rates continue to rise, it has been speculated that a higher Body Mass Index (BMI) stands alone as a health risk. However, there is substantial scientific evidence to support the notion that obesity in itself does not put an individual at increased risk of disease. The majority of epidemiological studies demonstrate that five pounds “underweight” is more harmful than 75 pounds “overweight”. [13][14][15][16][17] Furthermore, having a 'normal' BMI does not mean a person is necessarily healthy. The results of multiple studies have indicated that using weight alone as a criterion for health is off-target and potentially harmful.[18][19][20] This suggests that it is not possible to tell how healthy an individual is simply by looking at them or calculating their BMI.



Figure 1.2.3.3: Image by 272447 / Pixabay License

The following are measurable risk factors and markers of health that are independent of body weight. These are good targets for nutrition education and counseling and ways to monitor improvements of health status over time.

- Biomarkers: blood pressure, blood glucose, total cholesterol, high-density lipoproteins, low-density lipoproteins, triglycerides
- Regular movement/ activity/ exercise
- Fitness and ability to carry out daily tasks of living without undue fatigue
- Stress and inflammation
- Hormone balance
- Mental health status
- Sleep
- Quality of life
- Connection to the community
- Spiritual health
- Intellectual health
- Occupational health

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1.2.4: Comparing Diets

Learning Objectives

Compare and contrast conventional foods, modified foods, medical foods, and special dietary use foods.

Look at nutrition as a continuum of wellness, not just the absence of illness.

Diet Trends and Health

In the past, health was regarded merely as the absence of illness. However, a growing understanding of the complexity and potential of the human condition has prompted a new way of thinking about health. Today, we focus on the idea of wellness, which involves a great deal more than just not being sick. Wellness is a state of optimal well-being that enables an individual to maximize their potential. This concept includes a host of dimensions—physical, mental, emotional, social, environmental, and spiritual—which affect one's quality of life.[1] If one considers nutrition to be the foundation for good health, striving for wellness begins with an examination of dietary choices.

Dietary Food Trends

Hundreds of years ago, when food was less accessible and daily life required much more physical activity, people worried less about obesity and more about simply getting enough to eat. In today's industrialized nations, conveniences have solved some problems and introduced new ones, including hand-in-hand obesity and diabetes epidemics. As a result, fad diets gained popularity as more North Americans struggled with the cultural desire to drop excess pounds. However, new evidence-based approaches that emphasize more holistic measures are on the rise. These new dietary trends encourage those seeking to lose weight to eat foods in their whole form, while adopting a more active lifestyle, rather than strictly cutting calories. These newer approaches put dietary choices in the context of wellness and a healthier approach to life.

Functional Foods

Many people seek out foods that provide the greatest health benefits. This trend is giving rise to the idea of **functional foods**, which not only help meet basic nutritional needs but also are reported to fight illness and aging. According to the Academy of Nutrition and Dietetics (AND), formerly known as the American Dietetic Association, functional foods may reduce the risk of disease or promote optimal health. The AND recognizes four types of functional foods; they are: conventional foods, modified foods, medical foods, and special dietary use foods.[2]

The first group, **conventional foods**, represents the simplest form of functional foods. They are whole foods that have not been modified. Examples include whole fruits and vegetables (which are abundant in phytochemicals and antioxidants), yogurt and kefir (which contain natural probiotic bacteria that can help maintain digestive system health), and dark chocolate made with 70% or more cacao (which contains antioxidants).

Modified foods have been fortified, enriched, or enhanced with additional nutrients or bioactive compounds. Foods are modified using biotechnology to improve their nutritional value and health attributes. Examples of modified foods include calcium-fortified orange juice, breads enriched with B vitamins, iodized salt, cereals fortified with vitamins and minerals, or margarine enhanced with plant sterols. It is important to consider that the health claims of some modified foods may be debatable, or entirely fraudulent. Check with a licensed health professional, such as a registered dietitian nutritionist, regarding the effects of modified foods on your health.

Medical foods are designed for enteric administration under the guidance of a medical professional. Medical foods are created to meet very specific nutritional requirements. Examples of medical foods include liquid formulas for people with kidney disease, liver disease, diabetes, or other health issues. Medical food is also given to comatose patients through a gastronomy tube because they cannot eat by mouth.

Special dietary use foods do not have to be administered under a doctor's care and can be found in a variety of stores. Similar to medical foods, they address special dietary needs and meet the nutritional requirements of certain health conditions. For example, a bottled oral supplement administered under medical supervision is a medical food, but it becomes a special dietary use food when it is sold to retail customers. Examples of special dietary use foods include gluten-free foods, lactose-free dairy products, and formulas and meal replacement shakes.

Popular Diets

The concept of functional foods represents initiatives aimed at addressing health problems. Certain diet plans take this concept one step further, by striving to prevent or treat specific conditions. For example, it is widely understood that people with diabetes need to follow a particular diet. Although some of these diet plans may be nutritionally sound, use caution because some diets may be fads or be so extreme that they actually cause other health problems. Before experimenting with a diet, discuss your plans with a Registered Dietitian Nutritionist.

Throughout this section, we will discuss some of the more popular diets. Some fall under the category of potentially dangerous fad diets, while others are backed by scientific evidence for certain populations. Those that fall into the latter category provide a good foundation to build a solid regimen for optimal health.

Healthy Eating Patterns with Decades of Evidence Supporting their Benefits

The DASH Eating Plan

The Dietary Approaches to Stop Hypertension, or DASH Eating Plan, focuses on reducing sodium intake to either 2,300 milligrams per day (as recommended by the Dietary Guidelines for Americans) or 1,500 milligrams per day for certain populations. The DASH diet is an evidence-based eating plan that can help reduce high blood pressure. This plan may also decrease the risk of heart attack, stroke, diabetes, osteoporosis, and certain cancers.[3]

DASH tips to lower sodium include:

- Using spices instead of salt to add flavor
- Reading sodium content on processed or canned food labels, and choosing low-sodium options
- Removing some sodium from canned foods (such as beans) by rinsing the product before consumption
- Avoiding salt when cooking

DASH was designed with typical American eating preferences in mind, so this can be a good place to start for many. DASH dieters are recommended to consume a variety of whole grains and high-fiber fruits and vegetables, and moderate amounts of low-fat dairy products, lean meats, and heart-healthy fish. In addition, DASH limits the use of saturated fats to less than 7 percent of total calories and limits the consumption of sweets and alcohol. The DASH Eating Plan also calls for consuming less added sugar and drinking fewer sugar-sweetened drinks. It replaces red meat with fish and legumes and calls for increased calcium, magnesium, potassium, and fiber. Also, even though some people on the DASH diet may find it lowers their HDL (good) cholesterol along with their LDL (bad) cholesterol, it still has a positive cumulative effect on heart health.[4]

Curious to know what an example DASH Eating Plan menu looks like? Check out 'A Week With the DASH Eating Plan'.

The Mediterranean Diet

The Mediterranean diet incorporates many elements of the traditional dietary choices of people living in Greece and southern Italy. The Mediterranean diet focuses on a variety of nutrient-dense foods mostly from plant sources, including vegetables, fruits, whole grains, beans, nuts, seeds, and olive oil. It also limits the consumption of processed foods and recommends eating locally grown foods rich in micronutrients and antioxidants. Other aspects of this eating plan include consuming fish and poultry at least twice per week, eating red meat only a few times per month, and having up to seven eggs per week. Although drinking red wine in moderation used to be considered a beneficial aspect of the Mediterranean Diet, current research suggests that drinking is alcohol is always risky, and 0 drinks/week is now considered the healthiest option for overall health.

Unlike most diets, the Mediterranean diet does not cut fat consumption across the board. Instead, it incorporates low-fat cheese and dairy products, and it substitutes olive oil, canola oil, and other plant-based oils that are liquid at room temperature for butter and margarine.

More than fifty years of nutritional and epidemiological research has shown that people who follow the Mediterranean diet have some of the lowest rates of chronic disease and the highest rates of longevity among the populations of the world. Studies have shown that the Mediterranean diet also helps to decrease excess body weight, blood pressure, blood lipids, and blood sugar and insulin levels significantly.[10]

Although the Mediterranean diet has been widely celebrated for its health benefits, it is important to recognize that it represents a conceptual model rather than a single, uniform way of eating. The countries bordering the Mediterranean Sea have diverse culinary traditions influenced by geography, culture, religion, and socioeconomic factors. Moreover, the Mediterranean diet is not inherently superior to other traditional dietary patterns that share similar principles — namely, an emphasis on vegetables, fruits, beans, nuts, seeds, and whole grains, with limited intake of red and processed meats. Comparable plant-forward dietary models can be found in South and East Asia, as well as among many Indigenous communities in the Americas, where local, minimally processed foods have long supported health and sustainability.

Recent intervention studies, including the MIND (Mediterranean–DASH Intervention for Neurodegenerative Delay) diet trials — a hybrid of the Mediterranean and DASH (Dietary Approaches to Stop Hypertension) diets — have reinforced these benefits, demonstrating not only cardiovascular and metabolic improvements but also protective effects against cognitive decline and Alzheimer's disease. A systematic review of the scientific evidence suggests that higher adherence to the Mediterranean, DASH, or MIND diets is associated with less cognitive decline and a lower risk of Alzheimer's disease (van den Brink et al., 2019).

Tools for Change

For six years, researchers from the University of Bordeaux in France followed the dietary habits of more than seven thousand individuals age sixty-five and over. Participants who described greater consumption of extra-virgin olive oil reportedly lowered their risk of suffering a stroke by 41 percent. The study controlled for stroke risk factors, such as smoking, alcohol intake, high blood pressure, and a sedentary lifestyle. To increase the amount of olive oil in your diet, try spreading olive oil instead of butter on your toast, making your own salad dressing using olive oil, vinegar or lemon juice, and herbs, cooking with olive oil exclusively, or simply adding a dose of it to your favorite meal.[11]

Other Eating Patterns

The Gluten-Free Diet

The gluten-free diet helps people whose bodies cannot tolerate gluten, a protein found in wheat, barley, and rye. One of the most important ways to treat this condition is to avoid problematic foods, which is not easy. Although following a gluten-free diet is challenging, it is prescribed for patients with celiac disease, an autoimmune disorder with a genetic link. People who have celiac disease cannot consume gluten products without damaging their intestinal lining. Eating a gluten-free diet means finding replacements for bread, cereal, pasta, and more. It also means emphasizing fresh fruits, vegetables, and other foods without gluten. However, it is important to note that the gluten-free trend has become something of a fad even for those without a gluten intolerance. Celiac disease is a relatively rare condition found in less than 1 percent of the population. Therefore, a gluten-free diet should be followed only with a physician's recommendation.

Low-Carb Diets

Low-carb diets, which include the Atkins Diet and the South Beach Diet, focus on limiting carbohydrates—such as grains, fruit, and starchy vegetables—to promote weight loss. Other low-carb diets include the Paleolithic (Paleo) and Ketogenic (Keto) Diet. The Paleo diet mimics foods that humans theoretically consumed during the Stone Age or the Paleolithic period. This diet promotes higher amounts of grass-fed only animal protein, healthy fats, and non-starchy vegetables (i.e. okra, bok choy, carrots).[5] Similarly, the Keto diet highlights high protein intake and healthy fats, however there is more flexibility with the source of animal protein and it does not have to be limited to grass-fed.[6] Furthermore, the Paleo diet does not allow for dairy foods while the Keto diet allows dairy foods without added sugar.

The thinking behind the low-carb diet is that insulin prevents the breakdown of fat by allowing sugar in the form of blood glucose to be used for energy. Proponents of this approach believe that because limiting carbohydrates generally lowers insulin levels, it would then cause the body to burn stored fat instead. They believe this method not only brings about weight loss, but also reduces the risk factors for a number of conditions. However, some studies have shown that people who followed certain low-carb diet plans for two years lost an average of nearly 9 pounds, which is similar to the amount of weight lost on higher carbohydrate diets.[7]

The benefits of this kind of diet include an emphasis on whole, unprocessed foods and a de-emphasis of refined carbohydrates, such as white flour, white bread, and white sugar. However, there are a number of downsides. Typically, the first two weeks allow for only 20 grams of carbs per day, which can be dangerously low! The initial weight loss is water weight as carbohydrates bind to water in the body. In addition, dieters using the low-carb approach tend to consume twice as many saturated fats as people on a diet high in healthy carbohydrates, which is a known risk factor for heart disease. Low-carb diets are also associated with a higher energy intake, and the notion that "calories don't count," which is prevalent in this kind of diet, is not supported by scientific evidence.[8]

YouTube Video

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Figure 1.2.4.1: What is a Healthy Diet? (used with permission; Registered Dietitian Libby Parker)
Link: https://youtu.be/AS0Pk3Z6gWM

The Raw Food Diet

The raw food diet is followed by those who avoid cooking as much as possible in order to take advantage of the full nutrient content of foods. The principle behind raw foodism is that plant foods in their natural state are the most wholesome for the body. The raw food diet is not a weight-loss plan, it is a lifestyle choice. People who practice raw foodism eat only uncooked and unprocessed foods, emphasizing whole fruits and vegetables. Staples of the raw food diet include whole grains, dried fruits, seeds and nuts, seaweed, sprouts, and unprocessed produce. As a result, food preparation mostly involves peeling, chopping, blending, straining, and dehydrating fruits and vegetables.

The positive aspects of this eating method include consuming foods that are high in fiber and nutrients, and low in calories and saturated fat. However, the raw food diet offers little in the way of protein (especially if the consumer cannot eat nuts), and may lead to deficiencies of the vitamins A, D, E, and K and minerals including calcium. In addition, not all foods are healthier uncooked, such as spinach and tomatoes; and some foods such as dried beans can only be consumed if cooked. Also, cooking eliminates potentially harmful microorganisms that can cause foodborne illnesses. Therefore, people who primarily eat raw foods should thoroughly clean all fruit and vegetables before eating them. Poultry and other meats should always be cooked before eating.[12]

Vegetarian and Vegan Diets

Vegetarian and vegan diets have been followed for thousands of years for different reasons, including as part of a spiritual practice, to show respect for living things, for health reasons, or because of environmental concerns. For many people, being a vegetarian is a logical outgrowth of "thinking green." A meat-based food system requires more energy, land, and water resources than a plant-based food system. This may suggest that the plant-based diet is more sustainable than the average meat-based diet in the U.S. By avoiding animal flesh, vegetarians hope to look after their own health and that of the planet at the same time. Broadly speaking, vegetarians eat beans, grains, and fruits and vegetables, and do not eat red meat, poultry, seafood, or any other animal flesh. Some vegetarians, known as lacto-vegetarians, will eat dairy products. Others, known as lacto-ovo-vegetarians, will eat dairy products and eggs. A vegan diet is the most strict vegetarian diet—vegans do not eat dairy, eggs, or other animal products, and some do not eat honey because it is made by bees.

Vegetarian diets have a number of benefits. Well-designed eating plans can lower the risk of a number of chronic conditions, including heart disease, diabetes, and obesity. They also help to promote sustainable agriculture. However, if a vegetarian does not vary his or her food choices, the diet may be insufficient in calcium, iron, omega-3 fatty acids, zinc, and vitamin B_{12}. Also, if people who follow these diets do not plan out their meals, they may gravitate toward foods high in fats.

Table 1.2.4.1*: The Pros and Cons of Seven Popular Diets*

Diet	Pros	Cons
DASH Diet	• Recommended by the National Heart, Lung, and Blood Institute, the American Heart Association, and many physicians • Helps to lower blood pressure and cholesterol • Reduces risk of heart disease and stroke • Reduces risk of certain cancers • Reduces diabetes risk	• There are very few negative factors associated with the DASH diet • Limited options dining-out • Risk for hyponatremia (unlikely)
Mediterranean Diet	• Reduces the risk of cardiovascular disease and mortality • Reduces the risk of cancer • De-emphasizes processed foods and emphasizes whole foods and healthy fats • Lower sodium intake, due to fewer processed foods • Emphasis on monounsaturated fats leads to lower cholesterol • Highlighting fruits and vegetables raises consumption of antioxidants	• Does not specify daily serving amounts • Potential for high fat and high-calorie intake as nuts and oils are calorie-dense foods • Although drinking one to two glasses of wine per day is not a required component of the Mediterranean diet, those who choose to do so should know that drinking alcohol is always risky.
Gluten-Free Diet	• Reduces the symptoms of gluten intolerance, such as chronic diarrhea, cramping, constipation, and bloating • Promotes healing of the small intestines for people with celiac disease, preventing malnutrition • Might be beneficial for other autoimmune diseases, such as Parkinson's disease, rheumatoid arthritis, and multiple sclerosis	• Eliminating foods with gluten can lead to risk of folate, iron, thiamin, riboflavin, niacin, and vitamin B6 deficiencies • Special gluten-free products can be hard to find and expensive • Requires constant vigilance and careful food label reading, since gluten is found in many products
Low-Carb Diet	• Restricts refined carbohydrates, such as white flour and white sugar • May temporarily improve blood sugar or blood cholesterol levels	• Not entirely evidence-based • Results in higher fat and protein consumption than necessary • Does not meet the RDA for carbohydrates to provide glucose to the brain • Might increase risk of heart disease

Diet	Pros	Cons
Raw Food Diet	• Emphasizes whole foods • Focuses on nutritionally-rich foods	• Not entirely evidence-based • Very restrictive and limits protein and healthy fat intake • Could increase risk for foodborne illness • Extremely difficult to follow • High in fiber which can cause essential nutrient deficiencies • Some foods have better nutrient bioavailability when cooked
Vegetarianism and Veganism	• May reduce some chronic diseases such as cancer, heart disease, and Type 2 diabetes • More sustainable for the planet	• Higher risk for nutrient deficiencies such as protein, iron, zinc, omega-3 fatty acids, vitamin B12, and vitamin D • Consumption of a high-fiber diet interferes with mineral and nutrient bioavailability • Vegetarian and vegan protein sources are lower quality, with majority being low in at least one essential amino acid

Fad diets

A fad is defined by popular shared enthusiasm for something and is often short-lived. Examples include trends in clothing, music, hairstyles, and many more with which you are likely familiar. Food and health habits are not immune to these trends, and many of the dietary approaches discussed above can be described as fad diets. Just because a dietary approach is trending does not mean that it is bad, but popularity does not make it good either.

Fad diets are often associated with products. While these products potentially could be convenient or even helpful, the cost associated with purchasing these products may not necessarily be justified. Unfortunately, without some understanding of the purpose of the product or the need of the human body, many consumers are convinced by influencers or even pressured into spending money under the false perception that these products are necessary for good nutrition and health. This is almost always not the case, and these products should be evaluated on the basis of convenience or behavior perhaps, rather than biological need.

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1.2.5: Health At Every Size® and Intuitive Eating

Learning Objectives

Describe the benefits of following Health At Every Size® and Intuitive Eating principles, over typical dieting.

Understand that taking care of your body and health is achievable no matter your size.

Health at Every Size®

At its foundation, Health at Every Size® (HAES) supports behavior changes that create sustainable habits to improve health and promote a better quality of life.[21] The HAES approach is an alternative to the weight/size-based approach with a focus on improving health without a focus on weight loss. The research shows this model is able to promote sustainable improvements in health.

"In a study comparing the HAES model to a diet approach, though only dieters lost weight, both groups initially had similar improvements in metabolic fitness, activity levels, psychological measures, and eating behaviors. After two years, dieters had regained their weight and lost the health improvements, while the HAES group sustained their health improvements".[22]

The Health At Every Size® Principles are:

1. **Weight Inclusivity**: Accepting and respecting the diversity of body shapes and sizes
2. **Health Enhancement**: Recognizing that health and well-being are multi-dimensional and that they include physical, social, spiritual, occupational, emotional, and intellectual aspects
3. **Respectful Care**: Promoting all aspects of health and well-being for people of all sizes
4. **Eating for Well-being**: Promoting eating in a manner that balances individualized nutritional needs, hunger, satiety, appetite, and pleasure
5. **Life-Enhancing Movement**: Promoting individually appropriate, enjoyable, life-enhancing physical activity, rather than exercise that is focused on a goal of weight loss

The image below illustrates many elements that go into Health at Every Size® principle #2: Health Enhancement.



Figure 1.2.5.4: Image by Jennifer Draper / CC BY 4.0

Intuitive Eating

Intuitive eating is a non-diet approach to eating that promotes a connection to body cues of hunger and fullness and the selection of foods based on both pleasure and nutrient density.[24] When an individual is able to disconnect from diet culture and the focus on weight loss, they are able to eat in ways that support having energy throughout the day and feel competent around all foods. Instead of an outward focus on counting calories, dietary restriction, and measuring food portions, intuitive eating teaches a mindfulness practice of going inward and learning to respond to the cues and rhythms of the body. A review of 22 intervention studies that compared traditional weight loss to the intuitive eating approach concluded that the participants in the non-diet groups were able to stop unhealthy weight controlling behaviors, improve metabolic fitness and reduce risk factors, increase body satisfaction, and improve psychological distress.[25] Although the non-diet approach has not been shown to promote weight loss, a review of clinical trials concluded that intuitive eating was able to stabilize weight and help to prevent future weight gain, in addition to an improvement in blood pressure and cholesterol levels, and dietary intake.[26]



Figure 1.2.5.5: Image by CDC / Unsplash License

The 10 Principles of Intuitive Eating

1. **Reject the diet mentality** - Diets for weight loss "fail" at least 95% of the time. Let go of all the years of diet rules you've gathered.
2. **Honor your hunger** - Learn your hunger and fullness cues, and act on them. Your body knows what it needs.
3. **Make peace with food** - Letting go of judgments on food. There are no "good" or "bad" foods, just food.
4. **Challenge the food police** - Whether in your head or the people around you, challenge the "rules."
5. **Discover the satisfaction factor** - Food can and should be pleasurable and satisfying.
6. **Feel your fullness** - After a lifetime of trying to eat less, it can be hard to sit with the feeling of being full and content.
7. **Cope with your emotions with kindness -** Learn healthy ways of dealing with your emotional needs. Food won't fix them.
8. **Respect your body** - Your body deserves dignity today. Right now.
9. **Movement: Feel the difference** - Find ways of moving your body that are fun and "joyful," not to "burn calories."
10. **Honor your health – gentle nutrition** - Honor your health and taste preferences. There is no "perfect" eating, and we get to make food choices every day.

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1.2.6: Research Highlight - Maslow's Hierarchy of Needs

Learning Objectives

Review and critically evaluate a scholarly, peer-reviewed, primary research publication.

*Note: Each chapter of Introduction to Nutrition Science includes a Research Highlight like this one. The purpose of each of these is to extend your knowledge of the chapter content to relevant research. A primary research publication is one in which the results of the author's research contribute new knowledge to the field of study.

Introduction

In the following publication, author Ellyn Satter discusses the question, "How would it look to apply the principles of Maslow's Hierarchy of Needs to food management?" Indeed, "food" is listed as the first of the physiological needs that form the base of Maslow's Hierarchy of Needs pictured in Figure 2.71. Satter furthers this model by introducing a Food Hierarchy of Needs. As you read the publication linked below, consider the following questions:

1. What are your initial thoughts regarding the aim of this publication?
2. What is the question that the author is trying to answer with this publication?
3. What methods did the author use to determine an answer to the question?
4. What sorts of results did the author obtain, and how were those results analyzed?
5. What types of references does the author use to support the publication?
6. Do you agree with the conclusions to which the author came regarding an answer to the question?

Primary Publication

Satter E.M. (2007). Eating competence: Definition and evidence for the Satter eating competence model. *J Nutr Educ Behav (suppl)*; **39**: S142-S153. DOI: https://doi.org/10.1016/j.jneb.2007.01.003

Further evaluation

To evaluate this publication further, it might help to know a little more about Maslow's Hierarchy of Needs discussed in the publication. This theory in the field of Psychology was introduced by Abraham Maslow in 1943 as a means of describing human behavior. Although there is little scientific evidence to support the theory, it nevertheless enjoys continued popularity as a framework for understanding motivations and developmental growth in a wide variety of settings. Maslow's hierarchy of needs is illustrated here. In some versions of the pyramid, cognitive, and aesthetic needs are also included between esteem and self-actualization. Others include another tier at the top of the pyramid for self-transcendence.

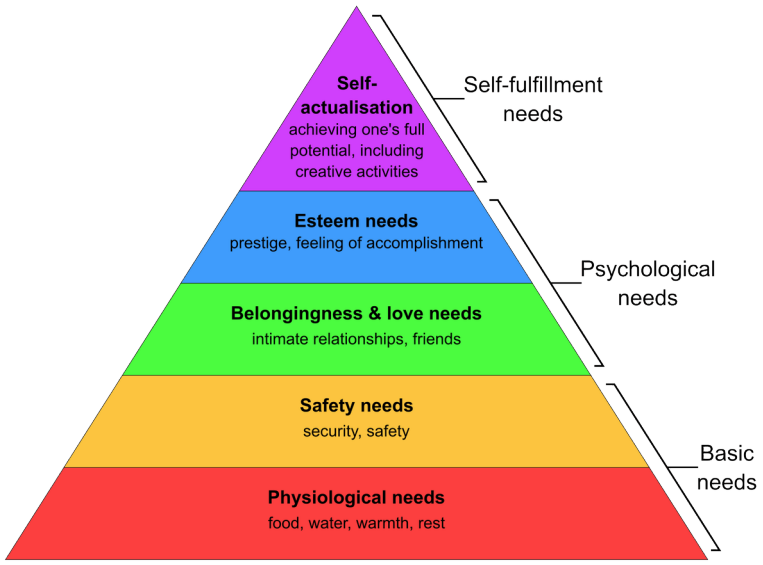


Figure 1.2.6.1: Maslow's Hierarchy of Needs By Androidmarsexpress - Own work, CC BY-SA 4.0

If you are interested in learning more, the following link is to a Maslow's Hierarchy of Needs Exercise from WISC-ONLINE, a non-profit service providing online learning objects covering a wide variety of subjects.

References

Attributions

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1.2.7: Diet Analysis Activity - Evaluating Food Responses

Learning Objectives

Utilize the "Food and Feelings Journal" to learn about your own eating patterns.

Many people who try traditional food journaling — tracking food, calorie, and macronutrient intake — report that they feel guilty and even more confused about food and their body than they did before starting the journal. This happens for a number of reasons, but most importantly, it's because the journal continually reinforces a message of failure.

Instead, you can try a "Food and Feelings Journal" (1).

The objective of this activity is to focus on how eating foods make a person feel afterward, rather than tracking Calories or nutrients. Using the table below, track a few days of eating - without numbers! Then look back and see if any patterns emerge. Do you eat alone a lot? If you feel you eat too much/binge at night do you notice that you haven't eaten much earlier in the day that might satisfy your hunger? What do you notice?

What actions can you consider taking after completing the Food and Feelings Journal analysis?

Time/who you are with/ where you are	**Thoughts/Feelings/Hunger level before eating**	**What you ate**	**Thoughts/Feelings/Hunger level after eating**

References:

1. Parker, Libby (2019). Permission To Eat.

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CHAPTER 2: NUTRITION SCIENCE AND INFORMATION LITERACY

Learning Objectives

After completing this unit, you should be able to:

1. Identify the sequential steps of the scientific method, and understand the importance of reporting research results in peer-reviewed journals and the value of scientific consensus.
2. Describe the different types of research studies used in nutrition, including the quality of evidence, advantages, and limitations of each.
3. Describe some of the limitations of nutrition research, including the challenges of studying complex dietary patterns and the influence of industry funding.
4. Identify the training and experience that leads to expertise in the field of nutrition, as well as career opportunities in the field.
5. Evaluate sources of nutrition information and distinguish between credible sources and those that are inaccurate or biased.

2.1: Introduction to Nutrition Science and Information Literacy

2.2: The Scientific Method

2.3: Types of Research Studies and How To Interpret Them

2.4: Healthy Skepticism in Nutrition Science

2.5: Who Are the Experts in Nutrition Science?

2.6: Fact-Checking Online Health and Nutrition Information

2.7: Finding Accurate Sources of Health and Nutrition Information

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2.1: Introduction to Nutrition Science and Information Literacy

If you follow nutrition science in the media for long enough, you'll start to see recurring themes. You'll see stories in the news about many of our favorite foods—like eggs, butter, coffee, and chocolate—that seem to flip-flop about whether these foods are good or bad for us. You'll notice seemingly eternal debates about whether dietary fat and carbohydrates are valuable macronutrients or villians. You'll watch as particular diets come in and out of fashion—and then back into fashion another decade or two later. And you'll see countless click-baity stories about the health benefits of eating so-called superfoods, or the dangers of eating others.



Figure 2.1.1: Photo by Brooke Cagle on Unsplash (license information)

Even if you don't pay much attention to nutrition science in the news, you'll hear a ton of conflicting opinions and information just by talking to the people around you. Maybe your best friend has gone gluten-free, your dad is on a keto diet, and your coworker swears the Whole 30 diet has been life-changing. They're all trying to convince you to join them in their latest diets, but your head is swimming. They can't all be right, and you don't want to just follow the latest fad. You want to find accurate information that's based on solid scientific evidence. How can you identify it in a sea of conflicting and overwhelming information? Who can you trust?

It can be hard to filter through it all, especially when it's attached to strong opinions, emotions, and people trying to sell their product or point-of-view. And yet, we all need to make choices about what to eat, at the very least for ourselves, and often for others. You may have the responsibility of feeding family members in different stages of life, with different needs and preferences. And if you work in the health professions, you may have patients or clients who look to you as a source of reliable information about nutrition. Of course, the problem of conflicting and overwhelming information is not unique to nutrition; you'll find the same issue in many other health-related fields, and beyond.

Now, more than ever, it's essential to develop skills in information literacy, including the ability to find information, evaluate whether it is accurate and useful, and apply it effectively. The purpose of this unit is to develop and hone your skills in information literacy as it applies to nutrition. You'll learn about the scientific method, because it forms the foundation of how we know what we know about nutrition. You'll learn about the different types of research studies and each of their advantages and limitations. We'll discuss various sources of information, such as scholarly and popular sources, how each of them can be useful in different ways, and how to evaluate them. We'll also discuss careers in nutrition and the different types of skills that you'll find among nutrition experts.

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2.2: The Scientific Method

Similar to the method by which a police detective investigates a crime, nutritional scientists discover the health effects of food and nutrients by first making an observation and posing a question that they'd like to answer. Then they formulate a hypothesis, test their hypothesis through experiments, and finally interpret the results. After analyzing additional evidence from multiple sources, they may form 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***.

The basis of what we know about nutrition is derived from research, and the scientific method underlies how research is conducted. The steps of the scientific method include:

1. **Observation/Question:** The researcher first makes an observation and comes up with a research question to investigate.

2. **Hypothesis:** The researcher formulates a hypothesis, or educated guess, that would explain the observation or question and that can be tested through scientific experiments.

3. **Experiment:** The researcher designs and conducts an experiment. A good design takes into account what has been done previously. Thus, before beginning a new study, the researcher undertakes a thorough review of published research in order to ensure that their work advances the field.

4. **Analysis:** The researcher collects and analyzes data that will either support or refute the hypothesis. If the hypothesis is not supported, researchers create a new hypothesis and conduct a new experiment. If the hypothesis is supported, researchers will design additional experiments to try to replicate the findings or to test them in different ways.

5. **Conclusion:** After multiple experiments consistently support a hypothesis, researchers can offer a conclusion or theory.



Figure 2.1. The scientific method is a cyclical process, because it always leads to new observations and questions.

Through the scientific method, our knowledge of science builds continuously over time. No single study is enough to fully explain any one phenomenon, particularly in an area as complex as nutrition. Even experiments that go exactly as expected lead us to new questions to investigate. Science is also filled with surprises, both big and small. Experiments may not yield the expected results, but unexpected results can lead to new and important questions. And because scientists are human, they can make mistakes along the way or fail to acknowledge or test an important variable, which is why it's important that experiments be repeated and evaluated by other researchers along the way. In fact, scientific advances rarely occur because of one person. Scientists usually tackle research projects in teams made up of people with different types of expertise, and **it generally takes multiple teams of researchers looking at the same question from different perspectives and through different approaches to reach a consensus—when scientists broadly agree on certain observations and interpretations of data**.

The history of nutrition is full of fascinating examples of the scientific method at work. One such example is the discovery that the mineral iodine is an essential nutrient. This story of scientific discovery began in 1811, when French chemist Bernard Courtois was isolating a substance called saltpeter, an ingredient needed to make gunpowder for Napoleon's army. Part of his isolation procedure involved burning seaweed, during which Courtois *observed* the release of an intense violet vapor, which crystallized when he exposed it to a cold surface. He sent the violet crystals to an expert on gasses, Joseph Gay-Lussac, who identified the crystal as a new element. It was named iodine after the Greek word for violet. But identifying iodine was just the beginning. The following timeline traces the scientific experiments, conducted by multiple investigators around the world, that were required to show that iodine is an essential nutrient.[1,2]

Early 1800s: Swiss physician Jean-Francois Coindet *observed* that eating seaweed was an effective cure for goiter, an enlargement of the thyroid gland in the neck. In 1813, he *hypothesized* that seaweed contained iodine and that he could use iodine instead of seaweed to treat his patients. He conducted an *experiment* by administering iodine tincture orally to his patients with goiter. The treatment worked, which Coindet *interpreted* as confirming his hypothesis that iodine tincture could treat goiter.



Figure 2.2. *A large goiter in a woman from India.*

Mid 1800s: Many other physicians contributed to the research on iodine deficiency and goiter. At the time, it was commonly believed that goiter was the result of poor hygiene, drunkenness, dampness, or contaminated water. But in 1851, French chemist Chatin *hypothesized* that the low levels of iodine found in food and water from certain areas far away from the ocean was the primary cause of goiter. In the late 1860s, authorities in several French villages began giving out iodine tablets and salt in an *experimental* effort to treat goiter. The program was effective, and 80 percent of goitrous children were cured. However, adults did not always respond well to the treatment, and because men with goiter were exempted from service in the French military, some people were opposed to treating it. Some scientists also insisted that goiter was caused by infectious disease, so iodine wasn't yet accepted as a means of preventing it.

Early 1900s: In 1918, Swiss doctor Bayard proposed iodizing salt as a way of increasing iodine intake in people living in areas where goiter was common. 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. In an *experimental* trial, the iodized salt was given to families to use for six months. It *resulted* in reduced incidence of goiter in this remote population. Later, Physician David Marine conducted the first U.S. *experiment* of treating goiter with iodized salt in Akron, Ohio.The study, conducted on over 4,000 school children, found that iodized salt prevented goiter. Seven other studies similar to Marine's were conducted in Italy and Switzerland, and they also demonstrated the effectiveness of iodized salt in treating goiter. In 1924, U.S. 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.

It took more than one hundred years **— and the work of many different scientists from around the world —** from iodine's discovery as an effective treatment for goiter until public health programs recognized it as such. During that time, there were no doubt many different theories about the cause of goiter and debate about how it should be treated and prevented.

Indeed, **uncertainty is a part of the scientific process.** Scientists must grapple with different possible explanations for their observations, and even as they may pursue one hypothesis, remain open-minded to alternative ones. Over time, as more evidence accumulates pointing toward a common conclusion, scientists reach a **consensus**, which the vast majority believe to be true. There is now a clear consensus that iodine deficiency causes goiter, and that iodizing salt is an effective means of preventing it.

Reporting Scientific Work

As we saw with the story of iodine research, scientists must share their findings in order for other researchers to expand and build upon their discoveries. Collaboration with other scientists when planning and conducting studies and analyzing results is important for scientific research. For this reason, communicating with peers and disseminating study results are important aspects of a scientist's work. Scientists can share results by presenting them at a scientific meeting or conference, but this approach can reach only the select few who are present. Instead, **most scientists present their results in peer-reviewed publications that are published in scientific journals**.

Peer-reviewed publications are scientific papers that are reviewed by a scientist's colleagues, or peers. These colleagues are qualified individuals, often experts in the same research area, who judge whether or not the scientist's work is suitable for publication. The process of peer review is a quality control step; its goal is to ensure that the research described in a scientific paper is original, significant, logical, and thorough. It's important to note that peer review doesn't mean a study is perfect or even good. Sometimes bad studies slip through peer review, but because they're published and other scientists read them, these are usually caught later and often retracted.

Peer review happens in other ways in science, too. When researchers apply for grants to fund their work, it is often other experts from their field that evaluate their grant proposals and help decide whether they should be funded. In a more informal way, researchers are reviewed by their peers when they present their findings at a conference.

Science is often messy and imperfect, but peer-review and publication of results are essential to its progress and ability to self-correct when people make mistakes.

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- "Reporting Scientific Work" section 5 from Jones, T.G. The Science of Biology, CC BY-NC-SA 4.0

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- [1]Carpenter, K. J. (2005). David Marine and the Problem of Goiter. *The Journal of Nutrition*, *135*(4), 675–680. https://doi.org/10.1093/jn/135.4.675
- [2]Zimmermann, M. B. (2008). Research on Iodine Deficiency and Goiter in the 19th and Early 20th Centuries. *The Journal of Nutrition*, *138*(11), 2060–2063. https://doi.org/10.1093/jn/138.11.2060

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2.3: Types of Research Studies and How To Interpret Them

The field of nutrition is dynamic, and our understanding and practices are always evolving. Nutrition scientists are continuously conducting new research and publishing their findings in peer-reviewed journals. This adds to scientific knowledge, but it's also of great interest to the public, so nutrition research often shows up in the news and other media sources. You might be interested in nutrition research to inform your own eating habits, or if you work in a health profession, so that you can give evidence-based advice to others. Making sense of science requires that you understand the types of research studies used and their limitations.

The Hierarchy of Nutrition Evidence

Researchers use many different types of study designs depending on the question they are trying to answer, as well as factors such as time, funding, and ethical considerations. The study design affects how we interpret the results and the strength of the evidence as it relates to real-life nutrition decisions. It can be helpful to think about the types of studies within a pyramid representing a hierarchy of evidence, where **the studies at the bottom of the pyramid usually give us the weakest evidence with the least relevance to real-life nutrition decisions, and the studies at the top offer the strongest evidence, with the most relevance to real-life nutrition decisions.**

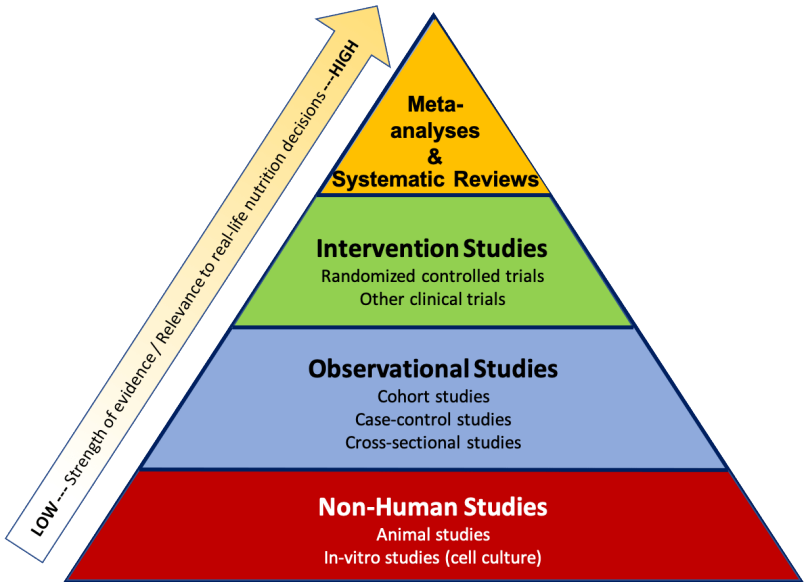


Figure 2.3. The hierarchy of evidence shows types of research studies relative to their strength of evidence and *relevance to real-life nutrition decisions, with the strongest studies at the top and the weakest at the bottom.*

The pyramid also represents a few other general ideas. There tend to be more studies published using the methods at the bottom of the pyramid, because they require less time, money, and other resources. **When researchers want to test a new hypothesis, they often start with the study designs at the bottom of the pyramid**, such as in vitro, animal, or observational studies. Intervention studies are more expensive and resource-intensive, so there are fewer of these types of studies conducted. But they also give us higher quality evidence, so they're an important next step if observational and non-human studies have shown promising results. Meta-analyses and systematic reviews combine the results of many studies already conducted, so they help researchers summarize scientific knowledge on a topic.

Non-Human Studies: In Vitro & Animal Studies

The simplest form of nutrition research is an ***in vitro study***. In vitro means "within glass," (although plastic is used more commonly today) and these experiments are conducted within flasks, dishes, plates, and test tubes. These studies are performed on isolated cells or tissue samples, so they're less expensive and time-intensive than animal or human studies. In vitro studies are vital for zooming in on biological mechanisms, to see how things work at the cellular or molecular level. However, these studies shouldn't be used to draw conclusions about how things work in humans (or even animals), because we can't assume that the

results will apply to a whole, living organism.





Animal studies are one form of ***in vivo*** research, which translates to "within the living." Rats and mice are the most common animals used in nutrition research. Animals are often used in research that would be unethical to conduct in humans. Another advantage of animal dietary studies is that researchers can control exactly what the animals eat. In human studies, researchers can tell subjects what to eat and even provide them with the food, but they may not stick to the planned diet. People are also not very good at estimating, recording, or reporting what they eat and in what quantities. In addition, animal studies typically do not cost as much as human studies.

There are some important limitations of animal research. First, an animal's metabolism and physiology are different from humans. Plus, animal models of disease (cancer, cardiovascular disease, etc.), although similar, are different from human diseases. Animal research is considered preliminary, and while it can be very important to the process of building scientific understanding and informing the types of studies that should be conducted in humans, animal studies shouldn't be considered relevant to real-life decisions about how people eat.

Observational Studies

Observational studies in human nutrition collect information on people's dietary patterns or nutrient intake and look for associations with health outcomes. Observational studies do not give participants a treatment or intervention; instead, they look at what they're already doing and see how it relates to their health. These types of study designs can only identify ***correlations*** (relationships) between nutrition and health; they can't show that one factor *causes* another. (For that, we need intervention studies, which we'll discuss in a moment.) Observational studies that describe factors correlated with human health are also called ***epidemiological studies***.[1]

One example of a nutrition hypothesis that has been investigated using observational studies is that eating a Mediterranean diet reduces the risk of developing cardiovascular disease. (A Mediterranean diet focuses on whole grains, fruits and vegetables, beans and other legumes, nuts, olive oil, herbs, and spices. It includes small amounts of animal protein (mostly fish), dairy, and red wine.[2]) There are three main types of observational studies, all of which could be used to test hypotheses about the Mediterranean diet:

- ***Cohort studies*** follow a group of people (a cohort) over time, measuring factors such as diet and health outcomes. A cohort study of the Mediterranean diet would ask a group of people to describe their diet, and then researchers would track them over time to see if those eating a Mediterranean diet had a lower incidence of cardiovascular disease.
- ***Case-control studies*** compare a group of cases and controls, looking for differences between the two groups that might explain their different health outcomes. For example, researchers might compare a group of people with cardiovascular disease with a group of healthy controls to see whether there were more controls or cases that followed a Mediterranean diet.
- ***Cross-sectional studies*** collect information about a population of people at one point in time. For example, a cross-sectional study might compare the dietary patterns of people from different countries to see if diet correlates with the prevalence of cardiovascular disease in the different countries.

Prospective cohort studies, which enroll a cohort and follow them into the future, are usually considered the strongest type of

observational study design. ***Retrospective*** studies look at what happened in the past, and they're considered weaker because they rely on people's memory of what they ate or how they felt in the past. There are several well-known examples of ***prospective*** cohort studies that have described important correlations between diet and disease:

- **Framingham Heart Study:** Beginning in 1948, this study has followed the residents of Framingham, Massachusetts to identify risk factors for heart disease.
- **Health Professionals Follow-Up Study:** This study started in 1986 and enrolled 51,529 male health professionals (dentists, pharmacists, optometrists, osteopathic physicians, podiatrists, and veterinarians), who complete diet questionnaires every 2 years.
- **Nurses Health Studies:** Beginning in 1976, these studies have enrolled three large cohorts of nurses with a total of 280,000 participants. Participants have completed detailed questionnaires about diet, other lifestyle factors (smoking and exercise, for example), and health outcomes.

Observational studies have the advantage of allowing researchers to study large groups of people in the real world, looking at the frequency and pattern of health outcomes and identifying factors that correlate with them. But even very large observational studies may not apply to the population as a whole. For example, the Health Professionals Follow-Up Study and the Nurses Health Studies include people with above-average knowledge of health. In many ways, this makes them ideal study subjects, because they may be more motivated to be part of the study and to fill out detailed questionnaires for years. However, the findings of these studies may not apply to people with less baseline knowledge of health.

We've already mentioned another important limitation of observational studies—that they can only determine correlation, not causation. A prospective cohort study that finds that people eating a Mediterranean diet have a lower incidence of heart disease can only show that the Mediterranean diet is *correlated* with lowered risk of heart disease. It can't show that the Mediterranean diet directly prevents heart disease. Why? There are a huge number of factors that determine health outcomes such as heart disease, and other factors might explain a correlation found in an observational study. For example, people who eat a Mediterranean diet might also be the same kind of people who exercise more, sleep more, have higher income (fish and nuts can be expensive!), or be less stressed. These are called ***confounding factors***; they're factors that can affect the outcome in question (i.e., heart disease) and also vary with the factor being studied (i.e., Mediterranean diet).

Intervention Studies

***Intervention studies*, also sometimes called experimental studies or clinical trials, include some type of treatment or change imposed by the researcher.** Examples of interventions in nutrition research include asking participants to change their diet, take a supplement, or change the time of day that they eat. Unlike observational studies, **intervention studies can provide evidence of cause and effect**, so they are higher in the hierarchy of evidence pyramid.

The gold standard for intervention studies is the ***randomized controlled trial (RCT).*** In an RCT, study subjects are recruited to participate in the study. They are then **randomly assigned** into one of at least two groups, one of which is a control group (this is what makes the study **controlled**). In an RCT to study the effects of the Mediterranean diet on cardiovascular disease development, researchers might ask the control group to follow a low-fat diet (typically recommended for heart disease prevention) and the intervention group to eat a Mediterrean diet. The study would continue for a defined period of time (usually years to study an outcome like heart disease), at which point the researchers would analyze their data to see if more people in the control or Mediterranean diet had heart attacks or strokes. Because the treatment and control groups were randomly assigned, they should be alike in every other way except for diet, so differences in heart disease could be attributed to the diet. This eliminates the problem of confounding factors found in observational research, and it's why RCTs can provide evidence of causation, not just correlation.

Imagine for a moment what would happen if the two groups weren't randomly assigned. What if the researchers let study participants choose which diet they'd like to adopt for the study? They might, for whatever reason, end up with more overweight people who smoke and have high blood pressure in the low-fat diet group, and more people who exercised regularly and had already been eating lots of olive oil and nuts for years in the Mediterranean diet group. If they found that the Mediterranean diet group had fewer heart attacks by the end of the study, they would have no way of knowing if this was because of the diet or because of the underlying differences in the groups. In other words, without randomization, their results would be compromised by confounding factors, with many of the same limitations as observational studies.

In an RCT of a supplement, the control group would receive a ***placebo—a* "fake" treatment that contains no active ingredients, such as a sugar pill.** The use of a placebo is necessary in medical research because of a phenomenon known as the placebo effect. The ***placebo effect*** results in a beneficial effect because of a subject's *belief* in the treatment, even though

there is no treatment actually being administered.

For example, imagine an athlete who consumes a sports drink and then runs 100 meters in 11.0 seconds. On a different day, under the exact same conditions, the athlete is given a Super Duper Sports Drink and again runs 100 meters, this time in 10.5 seconds. But what the athlete didn't know was that the Super Duper Sports Drink was the same as the regular sports drink—it just had a bit of food coloring added. There was nothing different between the drinks, but the athlete *believed* that the Super Duper Sports Drink was going to help him run faster, so he did. This improvement is due to the placebo effect. Ironically, a study similar to this example was published in 2015, demonstrating the power of the placebo effect on athletic performance.[3]

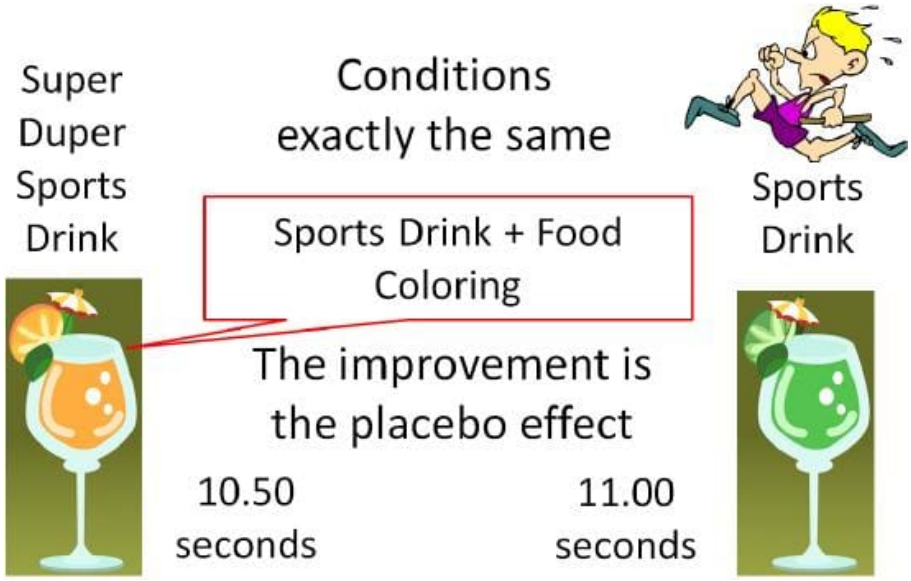


Figure 2.4. An example of the placebo effect

Blinding is a technique to prevent bias in intervention studies. In a study without blinding, the subject and the researchers both know what treatment the subject is receiving. This can lead to bias if the subject or researcher have expectations about the treatment working, so these types of trials are used less frequently. It's best if a study is ***double-blind*, meaning that neither the researcher nor the subject know what treatment the subject is receiving.** It's relatively simple to double-blind a study where subjects are receiving a placebo or treatment pill, because they could be formulated to look and taste the same. In a ***single-blind study***, either the researcher or the subject knows what treatment they're receiving, but not both. Studies of diets—such as the Mediterranean diet example—often can't be double-blinded because the study subjects know whether or not they're eating a lot of olive oil and nuts. However, the researchers who are checking participants' blood pressure or evaluating their medical records could be blinded to their treatment group, reducing the chance of bias.

Like all studies, RCTs and other intervention studies do have some limitations. They can be difficult to carry on for long periods of time and require that participants remain compliant with the intervention. They're also costly and often have smaller sample sizes. 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 its effects on pregnancy outcomes, because we know that alcohol consumption during pregnancy damages the developing fetus.)

YouTube Video

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VIDEO: "Not all scientific studies are created equal" by David H. Schwartz, YouTube (April 28, 2014), 4:26.

Meta-Analyses and Systematic Reviews

At the top of the hierarchy of evidence pyramid are systematic reviews and meta-analyses**.** You can think of these as "studies of studies." They attempt to combine all of the relevant studies that have been conducted on a research question and summarize their overall conclusions. Researchers conducting a ***systematic review*** formulate a research question and then systematically and independently identify, select, evaluate, and synthesize all high-quality evidence that relates to the research question. Since systematic reviews combine the results of many studies, they help researchers produce more reliable findings. A ***meta-analysis*** is a type of systematic review that goes one step further, combining the data from multiple studies and using statistics to summarize it, as if creating a mega-study from many smaller studies**.**[4]

However, even systematic reviews and meta-analyses aren't the final word on scientific questions. For one thing, they're only as good as the studies that they include. The Cochrane Collaboration is an international consortium of researchers who conduct systematic reviews in order to inform evidence-based healthcare, including nutrition, and their reviews are among the most well-regarded and rigorous in science. For the most recent Cochrane review of the Mediterranean diet and cardiovascular disease, two authors independently reviewed studies published on this question. Based on their inclusion criteria, 30 RCTs with a total of 12,461 participants were included in the final analysis. However, after evaluating and combining the data, the authors concluded that "despite the large number of included trials, there is still uncertainty regarding the effects of a Mediterranean-style diet on cardiovascular disease occurrence and risk factors in people both with and without cardiovascular disease already." Part of the reason for this uncertainty is that different trials found different results, and the quality of the studies was low to moderate. Some had problems with their randomization procedures, for example, and others were judged to have unreliable data. That doesn't make them useless, but it adds to the uncertainty about this question, and uncertainty pushes the field forward towards more and better studies. The Cochrane review authors noted that they found seven ongoing trials of the Mediterranean diet, so we can hope that they'll add more clarity to this question in the future.[5]

Science is an ongoing and often slow process, and uncertainty and evolving questions are inherently a part of that process. The scientific method is our best approach for building our understanding of how the world and human life works. Many different types of studies can contribute to scientific knowledge. None are perfect—all have limitations—and a single study is never the final word on a scientific question. Part of what advances science is that researchers are constantly checking each other's work, asking how it can be improved and what new questions it raises. And all of this moves us closer to consensus, usually built on a foundation of many different studies from every level of the hierarchy of evidence pyramid, and usually multiple meta-analyses of those studies.

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

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2.4: Healthy Skepticism in Nutrition Science

By this point in the unit, you should understand the types of studies used in nutrition research and the quality of evidence each can provide. As you sift through studies, there are a few limitations of nutrition research that are always worth keeping in mind:

- **Challenges in nutrition research:** There are some inherent challenges to researching what people eat and how it affects their health. This fact limits the quality of evidence and stirs controversy in nutrition research.
- **Influence of food industry funding:** Because government funding for nutrition research is limited, much of it is funded by the food industry. Industry's primary goal is to sell more of their products, so they have a conflict of interest that can result in bias in the way they design studies and interpret the results.

Being alert to these two things means always examining nutrition research with a healthy sense of skepticism. Let's take a closer look at these two issues in nutrition science.



Challenges in Nutrition Research

How does the food we eat affect our health? This question is exceedingly difficult to answer with certainty. We all need to eat every day, but we can choose from a huge array of possible foods in different combinations. And it's probably not what we eat on any given day that matters, but what we eat over months and years and decades—our long-term eating patterns—that matter to our long-term health.

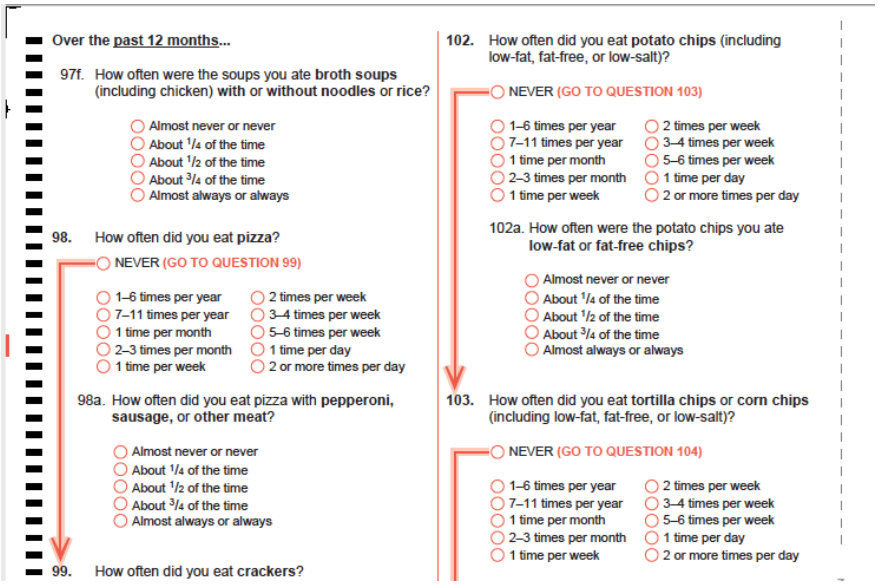
Imagine that you're a nutrition researcher, and you've made the **observation** that over the last 50 years in the U.S., people have been consuming more and more processed foods (foods made with refined ingredients and industrial processes, usually with the addition of sugar, fat, and/or salt). You **hypothesize** that processed foods are contributing to obesity, which has also increased over the last 50 years. You might first **test** your hypothesis in **animal studies** by feeding mice and rats a buffet of potato chips, soda, and Twinkies, and measuring changes in their body weight. You might find that the animals do, in fact, gain weight on this diet. However, you know that what is true in rodents isn't always true in humans, and you'll need to study humans in order to understand the role of processed foods in the obesity epidemic.

Your next step might be to conduct an **observational study**, the most common type of study design in human nutrition research. For example, you might do a **cross-sectional study** where you compare groups of people who eat a lot of processed foods with those who eat very little. Or you might conduct a **prospective cohort study** in which you ask people how much processed foods they eat and then follow them over time, looking for correlations between processed food consumption and their body composition.

These types of studies have been conducted, and they've found correlations between consumption of processed foods and obesity. For example, a cross-sectional study published in 2018 compared the consumption of processed foods and the prevalence of obesity in 19 European countries and found that countries where people eat more processed foods also have a greater prevalence of obesity.[1] A prospective cohort study published in 2016 followed nearly 8,500 university graduates in Spain and found that those who ate more processed foods were more likely to be overweight or obese 9 years later.[2]

From these results, can we conclude that eating more processed food *causes* weight gain? Nope. It's a tempting conclusion, but this brings us to the first major problem with nutrition research: **Observational studies can only show that two variables (eating processed foods and obesity, in this case) are *correlated*, not that one causes the other.** This distinction is especially important in nutrition because **diet is intertwined with many other lifestyle and socioeconomic factors that also affect health outcomes**. For example, people who eat more processed food might also eat fewer fruits and vegetables, exercise or sleep less, have more stress, or have less access to preventative healthcare. These are just a few of the **confounding factors** that could explain the observed correlation between processed food consumption and weight gain. Weight gain might have nothing to do with processed food and instead be driven by one or all of these factors, or others that we haven't considered.

The second major problem with observational nutrition research is that it's difficult to accurately quantify what and how much people eat, especially over long periods of time. Epidemiological studies usually rely on questionnaires that ask people to remember how much food they ate, but people are notoriously bad at remembering this type of information, and sometimes we fudge the truth. For example, you might remember that you had a cup of coffee but forget that you added cream, completely forget about a mid-morning muffin snack, or guess that you ate 2 cups of veggies when it was closer to 1.5 cups. And many diet questionnaires, called food frequency questionnaires, ask people to recollect and mentally average their food and beverage intake for the last 12 months, not just yesterday. The image below shows part of a page from a 24-page National Health and Nutrition Examination Survey (NHANES) food questionnaire, a national survey often used for research on country-wide dietary patterns. As you can see, these questions are detailed, and there's plenty of room for small errors to accumulate.



Over the past 12 months...

97f. How often were the soups you ate **broth soups** (including chicken) **with** or **without noodles** or **rice**?

- Almost never or never
- About 1/4 of the time
- About 1/2 of the time
- About 3/4 of the time
- Almost always or always

98. How often did you eat **pizza**?

- NEVER (GO TO QUESTION 99)
- 1–6 times per year
- 7–11 times per year
- 1 time per month
- 2–3 times per month
- 1 time per week
- 2 times per week
- 3–4 times per week
- 5–6 times per week
- 1 time per day
- 2 or more times per day

98a. How often did you eat pizza with **pepperoni, sausage, or other meat**?

- Almost never or never
- About 1/4 of the time
- About 1/2 of the time
- About 3/4 of the time
- Almost always or always

99. How often did you eat **crackers**?

102. How often did you eat **potato chips** (including low-fat, fat-free, or low-salt)?

- NEVER (GO TO QUESTION 103)
- 1–6 times per year
- 7–11 times per year
- 1 time per month
- 2–3 times per month
- 1 time per week
- 2 times per week
- 3–4 times per week
- 5–6 times per week
- 1 time per day
- 2 or more times per day

102a. How often were the potato chips you ate **low-fat** or **fat-free chips**?

- Almost never or never
- About 1/4 of the time
- About 1/2 of the time
- About 3/4 of the time
- Almost always or always

103. How often did you eat **tortilla chips** or **corn chips** (including low-fat, fat-free, or low-salt)?

- NEVER (GO TO QUESTION 104)
- 1–6 times per year
- 7–11 times per year
- 1 time per month
- 2–3 times per month
- 1 time per week
- 2 times per week
- 3–4 times per week
- 5–6 times per week
- 1 time per day
- 2 or more times per day

Figure 2.5. A sample page from the NHANES Food Questionnaire.

A third challenge in nutrition research is that diet is just so complex. Stanford physician and researcher John Ioannidis, a frequent critic of observational nutrition research, described the complexity of diet in a 2018 editorial published in JAMA: "Individuals consume thousands of chemicals in millions of possible daily combinations. For instance, there are more than 250,000 different foods and even more potentially edible items, with 300,000 edible plants alone." He also points out that how an individual responds to a particular dietary pattern can be influenced by genetics, age, and the way they metabolize nutrients. "Disentangling the potential influence on health outcomes of a single dietary component from these other variable is challenging, if not impossible," Ioannidis wrote.[3]



Returning to the question of processed foods, all three of these challenges impact how we interpret observational studies that show a correlation between processed food consumption and weight gain. It doesn't mean that these studies are useless, but we want to be aware of their limitations and consider other ways to test the hypothesis. One way to overcome these challenges is to conduct a **randomized controlled trial (RCT)**, the study design that gives us the highest quality evidence. RCTs are time and funding-intensive experiments, so they're usually only conducted after consistent evidence from observational and laboratory studies has accumulated.

It turns out that there has been a randomized controlled trial of processed foods and weight gain. It was funded by the National Institutes of Health and published in 2019 in the journal *Cell Metabolism*.[4] In this study, 20 participants lived in the NIH's Clinical Center for one month, where they consumed only processed foods for two weeks and only unprocessed foods for another two weeks, and they could eat as much or as little as they liked during each of these periods. The diets were carefully designed by dietitians so that they were matched in calories, sugar, fat, fiber, and macronutrients, and the exact amounts consumed by the participants were measured every day (solving the problem of measuring diet complexity and accurately describing what and how much people eat every day).

The study found that people ate about 500 kilocalories more and gained about a pound per week when they were eating processed foods. **This study design could show causation, not just correlation,** because the other nutritional factors like calories, sugar, fat, fiber, and macronutrients were held constant, and the diets were tested in the same people, so other factors such as genetics, sleep, stress, and exercise were constant between the two types of diets. (This was an example of a crossover randomized controlled trial, in which each subject serves as their own control, and they completed the processed and unprocessed phases of the trial in random order.)



Figure 2.6. At left, researchers Kevin Hall and Stephanie Chung talk with one of the processed foods trial participants at the NIH Clinical Center, an inpatient facility where participants lived for the duration of the study. At right, an NIH worker prepares meals for participants in the center's kitchen. All meals were provided for study participants to carefully control their diet during the trial.

This study suggested something very important—that food processing causes people to eat more food and gain weight. However, even the best study design has limitations. For one thing, this study was small (just 20 participants), and it only lasted for two weeks, so we don't know if the findings apply to the general population over a lifetime of complex, ever-changing diets. The next steps will be to try to repeat the study in another group of people to see if the finding holds and to design studies to figure out why processed foods cause increased caloric intake.

As you evaluate nutrition research, especially observational studies, keep in mind the inherent challenges of nutrition research and look for randomized controlled trials that can help solve those challenges. Even for randomized controlled trials, consider their limitations, and know that **one study is never enough to fully answer a question in the complex field of nutrition**.

Industry Influence: Follow the Money

Understanding how diet influences health is a pressing need. By some estimates, a suboptimal diet is the single greatest changeable risk factor contributing to death and disability worldwide, and in the United States, the cost of diet-related chronic diseases are estimated to be as high as $1 trillion each year.[5] Yet, for all its importance, nutrition science has long suffered from a lack of government investment, with only about 5 percent of the National Institutes of Health (NIH) budget, or $1.8 billion, directed towards research on how the foods we eat affect our health, according to a 2019 investigation by Politico. "In 2018, NIH funding for cancer, which affects just under 9 percent of the population, was $6.3 billion. Funding for obesity, which affects about 30 percent of the country, was about $1 billion," the article noted.[6]

With so little government funding for nutrition science, who is funding the rest of the studies that feed the constant news cycle? Many are funded by food companies and industry groups, either to conduct studies in their own research divisions or in the form of grants given to university scientists. That's problematic, because food companies and industry groups have an inherent bias or conflict of interest. Their primary goal is to promote their products and to sell more of them—not to advance knowledge of food and health—and this affects how they frame research questions, design and interpret studies, and report their results.

Marion Nestle, a retired nutrition professor at New York University, has written extensively about this problem. For a year in 2015-2016, she informally tracked industry-funded studies and found that 90 percent of the time, their conclusions benefited the industry that funded them. In another example, a 2013 meta-analysis found that among studies that looked at whether soda consumption contributed to obesity, those funded by the soda industry were five times more likely to conclude that it doesn't contribute to obesity compared to those not funded by the industry.[7] (Consider the processed foods RCT we just discussed. It was funded by the National Institutes of Health, which doesn't have a stake in the results. Would you trust the results of a study of processed foods if it was funded by Nabisco? Or for that matter, the Broccoli Growers of America? Probably not.)

There's likely a long history of biased nutrition research influencing dietary advice. For example, in the 1960s, the sugar industry paid well-respected academic scientists to publish research concluding that it was fat—not sugar—that was detrimental to heart health.[8] (Both too much fat and too much sugar can negatively affect heart health, but it benefited the sugar industry to focus the blame on fat.) As recently as 2015, Coca-Cola was funding research meant to promote lack of physical activity as the main cause of obesity, shifting blame away from dietary factors, such as drinking soda.[9] When corporations intentionally invest in research that takes attention from scientific findings that could harm their bottom line, they create more doubt and uncertainty, which can slow the process of reaching consensus and making policy changes that could improve people's health. There's a long history of this type of behavior, as described in a recent Scientific American article:

> *"Corporations and other interests with a financial or political stake in outcomes use **agnatogenesis—the deliberate creation of doubt**—to undermine confidence in scientific findings. Typically, the aim is to create enough uncertainty to stave off regulatory action. For example, the tobacco industry tried to cast doubt on findings linking smoking to cancer, and fossil fuel companies have tried to undermine scientific evidence of anthropogenic climate change."*[10]

Media attention has made researchers and policy makers much more aware of the problems with industry funding and conflicts of interest in nutrition research, and they're working to solve them. But regardless, if you see reports of a study that shows that blueberries can block bladder infections, pistachios can prevent pancreatitis, or cinnamon can cure cancer... Well, you should be skeptical, and always check the funding source. Studies on a single type of food are almost always industry-funded.

How to find clarity in a complex field

Let's review some of the key issues:

- Nutrition research is really difficult to do well. We want to know how nutrition relates to health over the long term, but it's hard to quantify how people eat over a lifetime and track them for long enough to see an impact.
- We often rely on observational studies, which can only show that two variables are *correlated*, not that one causes the other.
- Randomized controlled trials are rare, and they're often small, short-term studies that may or may not tell us what happens in the real world.
- Diet is exceptionally complex, with countless combinations of different nutrients and foods.
- One study is never enough to fully answer a question in the complex field of nutrition.
- Nutrition research is often funded by the food industry, which can be biased towards results that benefit business, not human health.

All of this can be discouraging, but you should also know that researchers are working hard to improve the quality of nutrition research and to interpret it honestly for the rest of us. As a consumer of nutrition information, use a skeptical eye when you read news of the latest nutrition research. Look for areas of consensus, where committees of experts have put their heads together to come up with the best advice they can based on the evidence we have, such as in the Dietary Guidelines for Americans. You'll find that while experts in this field are often debating the latest controversy, they also agree on a lot. As we continue on in this unit, we'll talk more about how to find accurate sources of information and who you can trust for evidence-based advice in the field of nutrition.

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2.5: Who Are the Experts in Nutrition Science?

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

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

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



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

This is not to dismiss other types of expertise that are related to food and nutrition. Traditional home cooks and formally-trained chefs have expertise in preparing tasty, comforting, or exciting food and in keeping food traditions alive. Farmers and home gardeners can share their knowledge about sustainable practices for producing food. Climate scientists can share how our food choices affect the health of the planet. And each of us has our own personal expertise in our own bodies, such as which foods seem to not agree with us, and which make us feel satisfied or energized or connected with our cultures. Knowledge about food can span many areas, but when it comes to information about how eating patterns affect our health, we want to look for someone with training and experience grounded in the science and practice of nutrition.

How to Spot an Expert

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

- Registered dietitian nutritionist (RD or RDN)
- Professional with advanced degree(s) (MS or PhD) in nutrition
- Physician (MD) with appropriate education and expertise in nutrition

Registered dietitians or professionals with advanced degrees in the field of nutrition are the most credible sources for sound nutrition advice, because their training was most likely grounded in science-based nutrition information and practice. Physicians can also be good sources of nutrition information, depending on their education and background. But be mindful that **medical schools generally offer minimal or no education and training in nutrition,** so most physicians have limited knowledge in this field unless they have sought out specific nutrition training on their own.

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

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

The video below delves further into how we can assess expertise in science and health, including some examples from the COVID-19 pandemic.

YouTube Video

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VIDEO: "Evaluate Expertise with Mike Caulfield" by CTRL-F, YouTube (May 22, 2020), 4:32.

Careers in Nutrition and Dietetics

There are several pathways to careers in nutrition and dietetics. Here's a quick run-down:

- **Nutrition and Dietetics Technician, Registered (NDTR)** – Earning this credential requires either a two-year associate's degree plus supervised practice in community programs, healthcare or foodservice facilities, or a four-year bachelor's degree from an accredited program. It also requires passing a national exam and completing continuing education to maintain registration. NDTRs often work under the supervision of an RD or RDN in healthcare, foodservice, community, and industry settings.[1]
- **Registered Dietitian Nutritionist (RD or RDN)** – As of January 1, 2024, earning the RD or RDN credential will require a graduate degree (master's or doctoral) in an approved program. The credential also requires completing a supervised internship program and passing a national exam, and continuing education is required to maintain registration.[2] There are many career opportunities for people with the RD and RDN credential, including in clinical practice, such as providing medical nutrition therapy for specific medical diagnoses. RDs and RDNs are also able to bill insurance for their services.
- **Nutritionist** – Unlike the RD/RDN and NDTR credential, there is no national standard for education and training for the

title “nutritionist.” Some states require individuals to meet certain education and training requirements and be licensed to practice as a nutritionist, but others have no such requirements. Thus, employment opportunities vary by state but are generally more limited (and do not include clinical work in healthcare settings) for those practicing without the RD/RDN or NDTR credential.[3]



Dietitians and nutritionists plan food and nutrition programs, promote healthy eating habits, and recommend dietary modifications. Typically, to work in a clinical setting like a hospital or outpatient setting, the RD/RDN credential is required. For example, a dietitian might teach a patient with hypertension how to follow a lower-sodium diet or formulate special diets for patients being fed through a tube. But there are many types of jobs in nutrition, including in government agencies, companies, education, community, and non-profit organizations. No matter the setting or the clientele, working in the field of nutrition means helping people improve their dietary habits by translating nutritional science into food choices.

Here are some examples of career settings for dietitians and nutritionists:

- Hospitals, clinics, long-term care, or other healthcare facilities, providing patient education and clinical care and tailoring foodservice and dietary recommendations to specific medical conditions and needs.
- Day and residential facilities, such as day care centers and correctional facilities, planning meals and food purchasing.
- Sports nutrition programs for teams, universities, or private clients, providing education and nutrition planning for athletes.
- Food and nutrition-related companies and industries, such as grocery stores and food and supplement companies, working in communications, marketing, public relations, product development, research, or consulting.
- Government agencies, administering federal food programs such as Women, Infants, and Children (WIC), Supplemental Nutrition Assistance Program (SNAP), or the National School Lunch Program (NSLP), coordinating communication campaigns, or creating or analyzing public policy.
- Private practice, providing individual nutrition screenings for clients and guidance on food-related issues, such as planning enjoyable meals, chronic disease prevention, treatment of eating disorders, and weight reduction.
- Community and public health settings, teaching and advising people about healthy eating habits.
- Universities and medical centers, teaching students about nutrition or working as part of research teams to plan and carry out scientific studies.
- Nonprofit organizations, such as anti-hunger organizations, food banks, public health organizations, and activist groups, providing nutrition-related expertise to help meet the organizations’ aims.

Whether you pursue nutrition as a career or simply work to improve your own dietary choices, what you are learning in this course is a step toward building your own expertise and being able to seek it out and recognize it in others.

Self-Check:

Query 2.5.1

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- [2]EatRightPro, Academy of Nutrition and Dietetics. *FAQs About Careers in Dietetics*. Retrieved June 3, 2023, from https://www.eatrightpro.org/acend/students-and-advancing-education/career-information/faqs-about-careers-in-dietetics
- [3]NutritionED. (2020, October 27). *Nutrition Jobs | Careers for Nutritionists and Dietitians*. https://www.nutritioned.org/careers/

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2.6: Fact-Checking Online Health and Nutrition Information

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

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

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

YouTube Video

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View this YouTube Video online

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

The SIFT Method

The SIFT method is one approach for quickly fact-checking an online information source. It was developed by Mike Caulfield, a research scientist at the University of Washington's Center for an Informed Public. The SIFT method includes 4 steps:

1. Stop
2. Investigate the source
3. Find better coverage
4. Trace claims to the original context



Figure 2.7. The Four Moves: Stop, investigate the source, find better coverage, trace the original context.

In this section, which is adapted from Mike Caulfield's writing, we'll look at how the SIFT method can help us to evaluate online health and nutrition information.

STOP.

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

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

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

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

INVESTIGATE the source.

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

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

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

YouTube Video

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VIDEO: "Lateral Reading" by UofL Research Assistance & Instruction, YouTube (June 26, 2020), 3:33.

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

YouTube Video

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

YouTube Video

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

FIND trusted coverage.

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

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

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

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

YouTube Video

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View this YouTube Video online

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

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

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

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

The video below gives an example of one technique that can help you trace media back to the original context: how to check an image.

YouTube Video

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View this YouTube Video online

VIDEO: "Skill – Check the Image" by CTRL-F, YouTube (September 27, 2019), 1:30.

The SIFT method is intended to be a quick way to fact-check claims. But sometimes, when you trace claims back to their original context, you'll find that the truth is more nuanced than originally presented. That's OK! Science is full of nuance and uncertainty. The following video gives you some tips for navigating these sticky fact-check situations.

YouTube Video

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VIDEO: "Skill: Advanced Claim Check" by CTRL-F, YouTube (September 11, 2020), 3:24.

Red Flags of Misinformation

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

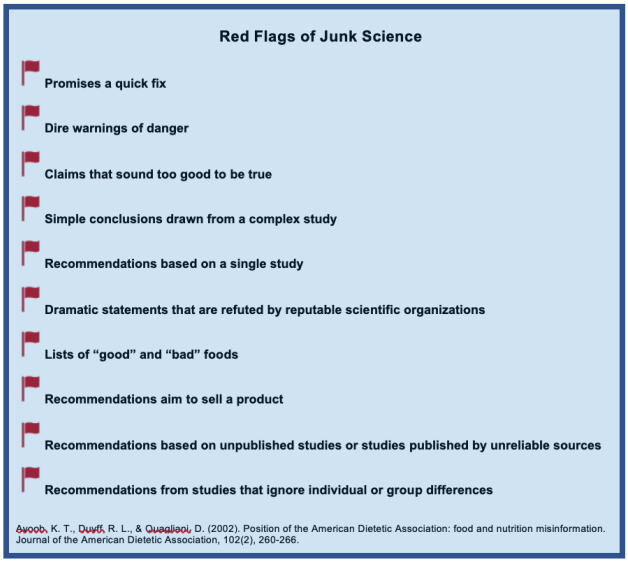


Figure 2.8. The Red Flags of Junk Science were written by the Food and Nutrition Science Alliance, a partnership of professional scientific associations, to help consumers critically evaluate nutrition information.

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

Self-Check Questions:

Query 2.6.1

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References:

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- [2]Ayoob, K.-T., Duyff, R. L., & Quagliani, D. (2002). Position of the American Dietetic Association: Food and Nutrition Misinformation. *Journal of the American Dietetic Association*, *102*(2), 260–266. https://doi.org/10.1016/S0002-8223(02)90062-3

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2.7: Finding Accurate Sources of Health and Nutrition Information

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

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



Searching for Online Health and Nutrition Information

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

- Government agencies, such as the National Institutes of Health (NIH), Food and Drug Administration (FDA), Centers for Disease Control and Prevention (CDC), and other websites ending in .gov, like PubMed and MedlinePlus.
- Colleges and universities, such as the Harvard School of Public Health (websites ending in .edu).
- Well-known healthcare and hospital systems, such as Mayo Clinic or Cleveland Clinic (websites usually ending in .org).
- Professional organizations, such as the Academy of Nutrition and Dietetics, the American Heart Association, the American College of Sports Medicine, the American Academy of Pediatrics, and the American Cancer Society (websites usually ending in .org).

We mention website domains because .gov and .edu sites are generally accurate sources of information. However, .org and .com domains are a mixed bag. Sites ending in .org generally represent organizations, including some of the trusted organizations listed above. But organizations can also be biased, and their sites may be more focused on pushing a certain agenda than

representing the scientific consensus. In fact, any entity can buy a .org domain. Likewise, .com websites can be valuable sources of information, or they may be more interested in selling you something. When you encounter a .org or .com site, you'll want to do more digging to understand the site's intent. If an organization is unfamiliar to you, practice lateral reading (e.g., a Wikipedia check) to learn more. Keep in mind that organizations can represent many different interests, and biased organizations can have names that are deceptively official-sounding.



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

- **Timeliness** — How old is the article? Because science is always evolving, articles published in about the last 5 years are preferred, as they'll have more current information. However, this isn't a hard and fast rule. Sometimes older articles provide important context, and sometimes an article that is even one year old is already out-of-date. (Think of how quickly information was emerging and changing during the COVID-19 pandemic!)
- **Relevance** — Is this information relevant to your topic? Or is it a distraction?
- **Credibility** — Does the information appear to be free of conflict of interest and bias? Does it cite or link to relevant peer-reviewed studies? Does it represent the findings accurately and fairly?
- **Expertise** — Whose expertise and views are represented? Based on what you learned earlier in this unit, do they have the appropriate expertise to provide accurate information on this topic?
- **Purpose** — What do you think is the purpose of this article or website? Is it intended to be educational? Is it an opinion piece, meant to convince you of one side or the other of an issue? Is it trying to get you to buy something or donate to a cause, or to attract more clicks? Is the language and layout inflammatory or extreme? Thinking about the author's purpose in creating the information or website can help you figure out if it is credible and useful to you.

Evaluating Health and Nutrition News

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

- **The news source should be reputable.** Larger, national news sources like the New York Times, Washington Post, and National Public Radio have dedicated health and science reporters who know how to evaluate studies and will seek out multiple experts to provide additional insights. They also have editors and fact checkers to double check their work.
- **The new study should be published in a peer-reviewed journal.** As you've learned, peer review is a system of checking the quality and interpretation of the research before it's published. Most studies that are truly newsworthy should have gone through the peer review process before we give them much attention. You'll sometimes see news stories about studies that have been presented at conferences or published as preprints (released before peer review); these may be interesting, but their conclusions should be viewed with caution.

- **The news article should provide context of previous research and comments from outside experts.** Remember that one study on its own doesn't usually tell us much, at least when it comes to making decisions about our own health. A good news article will tell us what was previously known about the topic and how the new study adds to our understanding. It will also include comments from experts who were not involved in the new study and who can discuss its limitations and relevance.



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

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

Building a Bank of Trustworthy Sources

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

US Government Websites:

- Centers for Disease Control and Prevention – https://www.cdc.gov
- ChooseMyPlate – https://www.choosemyplate.gov/
- Food and Drug Administration – http://www.fda.gov/
- Foodsafety.gov – https://www.foodsafety.gov/
- Healthy People – https://www.healthypeople.gov/
- MedlinePlus – https://medlineplus.gov/

- National Center for Complementary and Integrative Health – https://nccih.nih.gov/
- National Heart, Lung, and Blood Institute – https://www.nhlbi.nih.gov/health-topics
- National Institutes of Health Office of Dietary Supplements – https://ods.od.nih.gov/
- Nutrition.gov – https://www.nutrition.gov/
- Nutrition Evidence Systematic Review – https://nesr.usda.gov/
- Office on Women's Health – https://www.womenshealth.gov/
- Pubmed – https://pubmed.ncbi.nlm.nih.gov/

International Websites:

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

Education and Organization Websites:

- American Cancer Society – https://www.cancer.org/
- American Diabetes Association – http://www.diabetes.org/
- American Heart Association – https://www.heart.org/
- American Society for Nutrition – http://www.nutrition.org/
- Association for Size Diversity and Health – https://asdah.org/
- Center for Science in the Public Interest – https://cspinet.org/
- Eat Right (from the American Academy of Nutrition and Dietetics) – https://www.eatright.org/
- Family Doctor (from the American Academy of Family Physicians) – https://familydoctor.org/
- Food Allergy Research & Education – https://www.foodallergy.org/
- GI Patient Center (from the American Gastroenterological Association) – https://patient.gastro.org/
- Harvard School of Public Health – https://www.hsph.harvard.edu/nutrition/
- Healthy Children (from the American Academy of Pediatrics) – https://healthychildren.org
- Institute of Medicine: Food and Nutrition – http://nationalacademies.org/hmd/Global/Topics/Food-Nutrition.aspx
- Linus Pauling Institute – http://lpi.oregonstate.edu/
- Mayo Clinic – https://www.mayoclinic.org/
- National Eating Disorder Association – https://www.nationaleatingdisorders.org/
- Sugar Science – http://sugarscience.ucsf.edu/

News and Media Websites:

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

Self-Check:

Query 2.7.1

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CHAPTER 3: APPLYING NUTRITION SCIENCE — GUIDELINES AND TOOLS FOR HEALTHY EATING

Learning Objectives

After completing this unit, you should be able to:

1. Be able to define nutrition, food, and nutrients, and describe how nutrition is related to health, including risk of chronic disease.
2. Describe the different factors that impact food choices.
3. Understand the basic structure of molecules and that all nutrients are also chemical molecules.
4. Be able to describe the 6 types of nutrients and the various ways they are classified.
5. Understand how the Dietary Reference Intakes (DRI) are determined, what each type of DRI value means, and how they are used.
6. Be able to use the information in a Nutrition Facts label to understand the nutritional qualities of a food.
7. Be familiar with several concepts that are helpful in planning a healthful diet, including adequacy, balance, moderation, variety, nutrient density, and empty calories.
8. Be familiar with and able to use tools for planning a healthful diet, including MyPlate, Harvard Healthy Eating Plate, and the Dietary Guidelines for Americans.

3.1: Dietary Recommendations and Designing a Healthy Diet

3.1.1: What is a Healthy Diet?

3.1.2: Introduction to Designing a Healthy Diet

3.1.3: Classification of Nutrients

3.1.4: Defining Nutrient Requirements — Dietary Reference Intakes

3.1.5: Dietary Guidelines for Americans

3.1.6: MyPlate, DASH, and The Mediterranean Diet

3.1.7: Reading and Understanding Nutrition Facts labels

3.1.8: Navigating Portion Sizes

3.1.9: Ultra-processed Foods (UPF)

3.2: Assessing Alignment with the DGA, Physical Activity Goals, and Healthy People 2030 Goals

3.2.1: NHANES — National Health and Nutrition Examination Survey

3.2.2: Healthy Eating Index (HEI)

3.2.3: National Goals for Nutrition and Health — Healthy People 2030

3.2.4: Physical Activity and Lifestyle

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3.1: DIETARY RECOMMENDATIONS AND DESIGNING A HEALTHY DIET

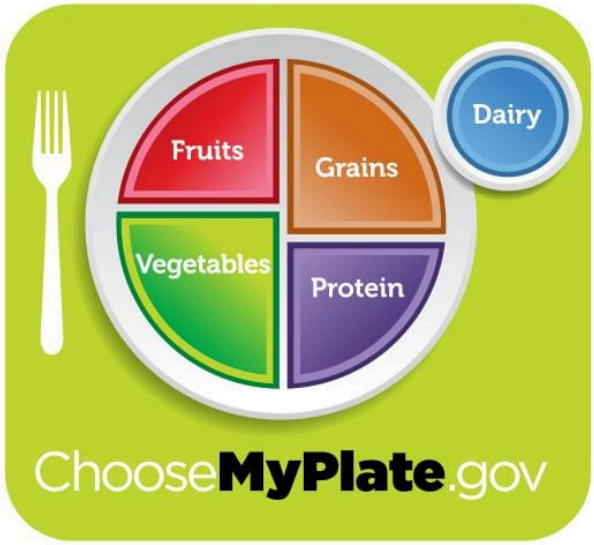


Figure 3.1.1: ChooseMyPlate image by U. S. Department of Agriculture / Public Domain

3.1.1: What is a Healthy Diet?

3.1.2: Introduction to Designing a Healthy Diet

3.1.3: Classification of Nutrients

3.1.4: Defining Nutrient Requirements — Dietary Reference Intakes

3.1.5: Dietary Guidelines for Americans

3.1.6: MyPlate, DASH, and The Mediterranean Diet

3.1.7: Reading and Understanding Nutrition Facts labels

3.1.8: Navigating Portion Sizes

3.1.9: Ultra-processed Foods (UPF)

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3.1.1: What is a Healthy Diet?

Learning Objectives

- Define the components of a healthful diet.

Good nutrition means eating the right foods, in the right amounts, to receive enough (but not too much) of the essential nutrients so that the body can remain free from disease, grow properly, work effectively, and feel its best. The phrase “you are what you eat” refers to the fact that the food you eat has cumulative effects on the body. And many of the nutrients obtained from food do become a part of us. For example, the protein and calcium found in milk can be used in the formation of bone. The foods we eat also impact how we feel—both today and in the future. Below we will discuss the key components of a healthy diet that will help prevent chronic disease (like heart disease and diabetes), maintain a healthy weight, and promote overall health.

Achieving a Healthy Diet

Achieving a healthy diet is a matter of balancing the quality and quantity of food that you eat to provide an appropriate combination of energy and nutrients. There are five key characteristics that make up a healthful diet:

1. Adequacy
2. Proportionality
3. Nutrient density
4. Moderation
5. Variety

Adequacy

A diet is **adequate** when it provides sufficient amounts of calories and each essential nutrient, as well as fiber. Most Americans report not getting enough fruit, vegetables, whole grains or dairy, which may mean falling short in the essential vitamins and minerals found in these food groups, like Vitamin C, potassium, and calcium, as well as fiber.[1]

Proportionality

Proportionality (sometimes referred to as a 'balanced diet') is a key concept in building a healthy eating pattern, and the MyPlate pictogram visually represents this by showing the relative amounts of each food group that should be included in a balanced meal. On the MyPlate icon, fruits and vegetables together make up half the plate, with vegetables occupying a slightly larger portion than fruits, highlighting their importance in providing essential nutrients and dietary fiber. Grains and protein foods make up the other half, with a greater emphasis on grains — especially whole grains. A serving of dairy, such as a cup of milk or yogurt, is shown alongside the plate, reinforcing its role in contributing calcium, vitamin D, and other vital nutrients. This proportional layout encourages individuals to make healthier food choices by emphasizing nutrient-dense foods in appropriate amounts, supporting overall health and well-being.

Image 3.1.1.1: “MyPlate pictogram” by USDA is licensed under CC BY 2.0

In practice, this means eating a combination of foods from the different food groups, in the right proportions relative to each other. Because these food groups provide different nutrients, following MyPlate recommendations is likely to support adequate nutrient intake. For example, vegetables are an important source of potassium, dietary fiber, folate, vitamin A, and vitamin C, whereas grains provide B vitamins (thiamin, riboflavin, niacin, and folate) and minerals (iron, magnesium, and selenium). No one food or food group is more important than the other. It is the combination of all the different food groups — fruit, vegetables, grains, dairy, & protein foods — that will ensure an adequate diet.

Although not shown on the MyPlate pictogram, **oils are also an important component of a healthy diet.** Oils are lipids (fats) that are liquid at room temperature, like vegetable oils used in cooking. They come from many different plants and from fish. Oils provide important nutrients such as unsaturated fats and vitamin E. Choosing unsaturated fat in place of saturated fat can reduce a person's risk of heart disease and improve “good” (HDL) cholesterol levels. **Please note:** The fat from some tropical plants like **coconut oil, palm oil, and palm kernel oil** *are* ***not included in the oils category*** because they are higher in saturated fats than other oils. They can be thought of as solid fats. Solid fats are fats that are solid at room temperature, like butter, lard and shortening. Solid fats come from many animal foods and can be made from vegetable oils.



Image 3.1.1.1: “Four Days of Bento” by Blairwang is licensed under CC BY 2.0

Nutrient Density

Nutrient Density is a measure of the nutrients that we’re usually trying to consume more of—vitamins, minerals, fiber and protein—per calorie of food, coupled with little or no solid fats, added sugars, refined starches, and sodium. For example, in the screenshot below, a 90 percent lean 3-ounce ground beef patty is considered more nutrient-dense than a 75 percent lean patty. In the 90 percent lean patty, for 184 calories you get protein, iron, and other needed nutrients. On the other hand, the 75 percent lean patty has 236 calories, but the extra 52 calories add only solid fats and no other appreciable nutrients.

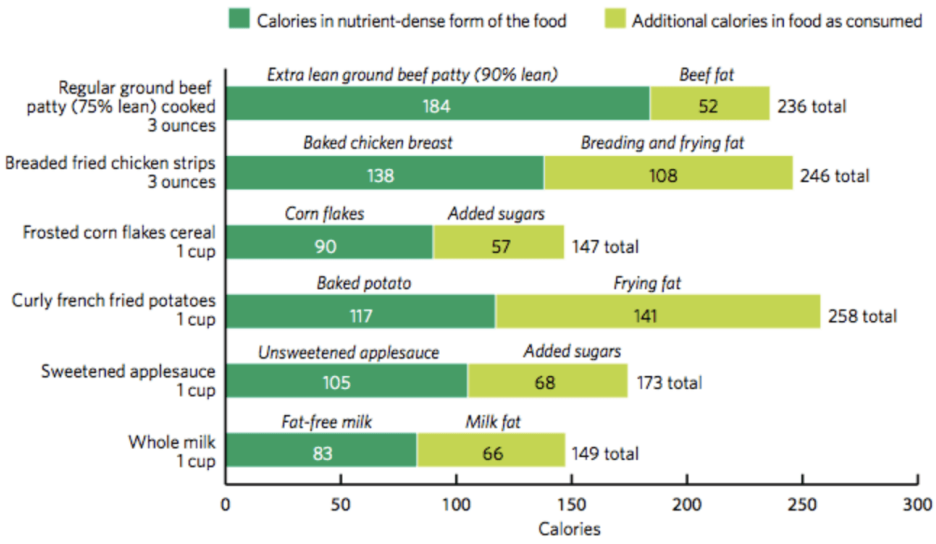


Figure 3.1.1.1: Examples of the calories found in nutrient-dense food choices compared with calories found in less nutrient-dense forms of these foods. "Examples of the calories in food choices that are not in nutrient dense forms and the calories in nutrient dense forms of these foods" by The Dietary Guidelines for Americans 2010, Figure 2.2, is in the Public Domain

All vegetables, fruits, whole grains, seafood, eggs, beans and peas, unsalted nuts and seeds, fat-free and low-fat dairy products, and lean meats and poultry — when prepared with little or no added solid fats, and sugars — are nutrient-dense foods.

Foods become less nutrient dense when they contain **empty calories** — calories from solid fats and/or added sugars. Solid fats and added sugars add calories to a food but don't provide other nutrients. Foods with empty calories have fewer nutrients per calorie; therefore, they are less nutrient dense.

Examples of foods HIGH in empty calories:

- doughnuts, cakes, cookies
- sweetened cereals and yogurt
- sweetened beverages
- high-fat meats
- fried foods
- alcohol

Examples of nutrient-dense foods:

- whole grains like brown rice, whole wheat bread and pasta, barley, and oatmeal
- plain, nonfat milk and yogurt
- beans, nuts, and seeds
- lean meats
- whole, fresh fruits and vegetables

You can choose more nutrient-dense foods by making small modifications to your current eating pattern. Examples include preparing foods with less fat by baking versus frying, purchasing items like cereals and fruits with less added sugar, and focusing on eating foods in their natural state versus adding a lot of extra fat, sugar and sodium.

Keep in mind that empty calories are not always a bad thing. In fact, empty calories can help promote eating more nutrient-dense foods. Adding a little fat and/or sugar to nutrient-dense foods can add flavor, making the food more enjoyable. A teaspoon of sugar in oatmeal, or a teaspoon of butter on steamed veggies is a great way to include empty calories. In these cases, the calories come packaged with other nutrients (since they are added to whole foods), whereas the empty calories in soda come with no other nutrients, only added sugar.

Table 3.1.1.1: 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 or lean ham
Fried chicken	Baked chicken with herbs
White bread, white rice	Whole-grain bread, brown rice
Sweetened cereals	Minimally sweetened cereals with fresh fruit
Apple or berry pie	Fresh apple or berries
Deep-fried French fries	Oven-baked French fries or sweet potato baked fries
Fried vegetables	Steamed or roasted vegetables
Sugary sweetened soft drinks	Water, or seltzer mixed with 100 percent fruit juice
High-sodium canned beans	Low-sodium canned beans or home-cooked dried beans
Canned fruit in syrup	Fresh or frozen fruit without added sugars

Moderation

Moderation means not eating to the extremes, neither too much nor too little of any one food or nutrient. Moderation means that small portions of higher-calorie, lower-nutrient foods like chips and candy can fit within a healthy diet. Including these types of foods can make healthy eating more enjoyable and also more sustainable. When eating becomes too extreme—where many foods are forbidden—this eating pattern is often short-lived until forbidden foods are overeaten. Too many food rules can lead to a cycle of restriction-deprivation-overeating-guilt.[2] For sustainable, long-term health benefits, it is important to give yourself permission to eat all foods.



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Variety

Variety refers to consuming different foods within each of the food groups on a regular basis. Because no single food or food

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

References

1. U.S. Department of Agriculture and U.S. Department of Health and Human Services. (2020). Dietary Guidelines for Americans, 2020-2025, 9th Edition. Retrieved from https://www.dietaryguidelines.gov/
2. Rumsey, A. (2018, Janurary 8) Why Eating Fewer Calories Won't Help You Lose Weight. U.S. News. Retrieved from https://health.usnews.com/health-news/blogs/eat-run/articles/2018-01-08/why-eating-fewer-calories-wont-help-you-lose-weight

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Learning Check 3.1.1.1

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3.1.2: Introduction to Designing a Healthy Diet

What makes a diet “healthy”? What does the word “healthy” even mean? Each of us might picture something different when we think of a healthy diet, and if you travel around the world, you’ll find even more variation in how people define this term.

Indeed, humans are incredibly flexible when it comes to food. We are omnivores, and we can survive and thrive on a wide variety of different foods. The foods that nourish our bodies are often the same foods that nourish our souls, bringing us together with friends and family, celebrating traditions and conjuring memories of meals past.



Figure 3.1.2.1: Person cooking at a table photo by Markus Winkler on Unsplash (license information)

We’ll begin our study of nutrition by zooming in on nutrients—the molecules in food that nourish us—to begin to understand what each gives us. Then, we’ll zoom back out to consider some tools for choosing foods that will together provide us with all the nutrients we need. Because whatever the deep and complex meanings that food brings to our lives and our culture, we also want to choose foods that will enable us to be well, to fuel our activities, to prevent disease, and to live long, healthy lives.

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3.1.3: Classification of Nutrients

Food is one of life's greatest pleasures. It offers amazing flavors, aromas, and textures. Food also provides our body with essential nutrients and non-nutrients like phytochemicals, both of which are vital to health. This section will discuss the six classes of nutrients and how these nutrients can be classified.

What are Nutrients?

Nutrients are chemical substances found in food that are required by the body to provide energy, give the body structure, and help regulate chemical processes. **There are six classes of nutrients:**

1. carbohydrates
2. lipids
3. proteins
4. water
5. vitamins
6. minerals

Nutrients can be further classified as either ***macronutrients*** or ***micronutrients*** and either ***organic*** or ***inorganic***, as well as whether or not they provide energy to the body (***energy-yielding***). We'll discuss these different ways of classifying nutrients in the following sections.

Macronutrients

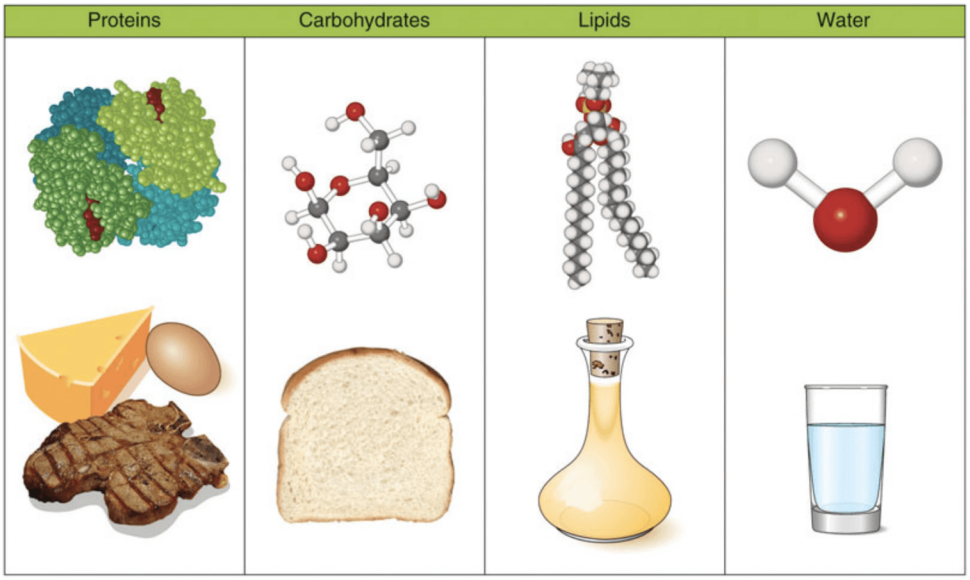


Figure 1.5. Macronutrients include proteins, carbohydrates, lipids, and water. This figure illustrates each nutrient's chemical structure and examples of food sources.

Carbohydrates

Carbohydrates are molecules composed of carbon, hydrogen, and oxygen. The major food sources of carbohydrates are grains, dairy products, fruits, legumes, and starchy vegetables, like potatoes. Non-starchy vegetables, like carrots, also contain carbohydrates, but in lesser quantities.

Carbohydrates are broadly classified into two groups based on their chemical structure: simple carbohydrates (often called simple sugars) and complex carbohydrates, which include fiber, starch, and glycogen. Carbohydrates are a major fuel source for all cells of the body, and certain cells, like cells of the central nervous system and red blood cells, rely solely on carbohydrates for energy.

Lipids

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

Proteins

Proteins are large molecules composed of chains of amino acids, which are simple subunits made of carbon, oxygen, hydrogen, and nitrogen. Food sources of proteins include meats, dairy products, seafood, and a variety of plant-based foods, like beans, nuts, and seeds. The word protein comes from a Greek word meaning “of primary importance,” which is an apt description of these macronutrients as they are also known as the “workhorses” of life. Proteins provide structure to bones, muscles, and skin, and they play a role in conducting most of the chemical reactions occurring in the body. Scientists estimate that more than 100,000 different proteins exist within the human body. Proteins can also provide energy, though this is a relatively minor function, as carbohydrates and fat are preferred energy sources.

Water

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

Micronutrients

Micronutrients are nutrients required by the body in smaller amounts, but they’re still essential for carrying out bodily functions. Micronutrients include all of the essential minerals and vitamins. There are 16 essential minerals and 13 essential vitamins (Table 1.1 and Table 1.2). In contrast to carbohydrates, lipids, and proteins, micronutrients are not a source of energy, but they assist in the process of energy metabolism as cofactors or components of enzymes (known as coenzymes). ***Enzymes*** are proteins that catalyze (or accelerate) chemical reactions in the body; they’re involved in all aspects of body functions, including producing energy, digesting nutrients, and building macromolecules.

Minerals

Minerals are inorganic substances that are classified depending on how much the body requires. ***Trace minerals***, such as molybdenum, selenium, zinc, iron, and iodine, are only required in amounts of a few milligrams or less per day. ***Major minerals***, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in amounts of hundreds of milligrams or more per day. Many minerals are critical for enzyme function, and others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals in the body. To give you an appreciation of the many functions of minerals, the table below has a complete list of all the minerals and their major functions. (Note: There is no need to memorize these minerals and functions at this point in the course.)

Major Minerals	Major Function
Sodium	Fluid balance, nerve transmission, muscle contraction
Chloride	Fluid balance, stomach acid production
Potassium	Fluid balance, nerve transmission, muscle contraction
Calcium	Bone and teeth health maintenance, nerve transmission, muscle contraction, blood clotting
Phosphorus	Bone and teeth health maintenance, acid-base balance
Magnesium	Protein production, nerve transmission, muscle contraction
Sulfur	Protein production
Trace Minerals	**Function**
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

Table 1.1. Minerals and their major functions

Vitamins

Vitamins are organic nutrients that are categorized based on their solubility in water. The ***water-soluble vitamins*** are vitamin C and all of the B vitamins. The ***fat-soluble vitamins*** are vitamins 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 function. To give you an appreciation of the many functions of vitamins, the table below lists the 13 essential vitamins and their major functions. (Note: There is no need to memorize these vitamins and functions at this point in the course.)

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

E	Antioxidant, cell membrane protection
K	Bone and teeth health maintenance, blood clotting

Table 1.2. Vitamins and their major functions

As you might suspect based on the major functions of vitamins listed above, vitamin deficiencies can cause severe health problems and even death. For example, a deficiency in niacin causes a disease called pellagra, which was common in the early twentieth century in some parts of the United States. The common signs and symptoms of pellagra are known as the "4D's—diarrhea, dermatitis, dementia, and death." Until scientists discovered that better diets relieved the signs and symptoms of pellagra, many people with the disease ended up hospitalized and in asylums awaiting death. The following video gives an overview of pellagra and how its cure was discovered through a change in diet.

YouTube Video

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VIDEO: "Pellagra video" by Teresa Johnson, YouTube (June 20, 2012), 5:49 minutes.

Energy-Yielding Nutrients

The macronutrients—carbohydrate, protein, and fat—are the only nutrients that provide energy to the body. The energy from macronutrients comes from their chemical bonds. This chemical energy is converted into cellular energy that can be utilized to perform work, allowing cells to conduct their basic functions. **Although vitamins also have energy in their chemical bonds, our bodies do not make the enzymes to break these bonds and release this energy.** (This is fortunate, as we need vitamins for their specific functions, and breaking them down to use for energy would be a waste.)

Food energy is measured in kilocalories (kcals). A kilocalorie is the amount of energy needed to raise 1 kilogram of water by 1 degree Celsius. The kilocalories stored in food can be determined by putting the food into a bomb calorimeter and measuring the energy output (energy = heat produced).

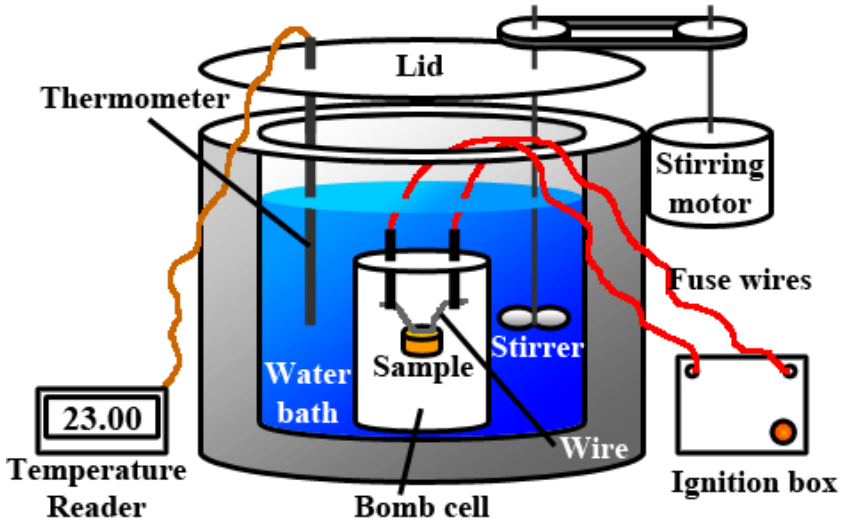


Figure 1.6. A Bomb calorimeter

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VIDEO: "Bomb Calorimetry" by David Read, YouTube (September 16, 2008), 2:19 minutes.

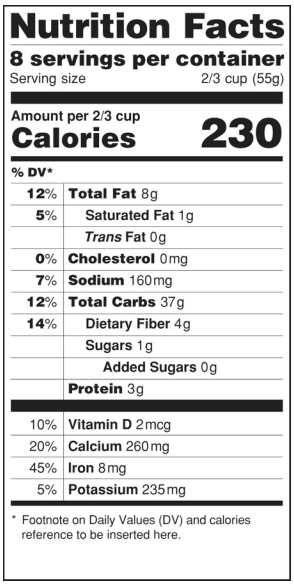
In the US, the kilocalorie (kcal) is the most commonly used unit of energy and is often just referred to as a calorie. Strictly speaking, a kcal is 1000 calories. In nutrition, the term calories almost always refers to kcals. Sometimes the kcal is indicated by capitalizing calories as "Calories." For the sake of simplicity, we'll use the terms "calories" and "kilocalories" interchangeably in this book.

Below is a list of energy sources in the diet from lowest to highest calories per gram (a gram is about the weight of a paperclip). Notice the addition of alcohol. Although alcohol does provide energy, it isn't a nutrient, because it isn't required as a source of nourishment to the body.

Energy Sources (kcal/g)

- Carbohydrates 4
- Protein 4
- Alcohol 7
- Lipids 9

Carbohydrates and proteins provide 4 calories per gram, and fats provide 9 calories per gram. Fat is the most energy-dense nutrient, because it provides the most calories per gram (more than double carbohydrates and protein).



Nutrition Facts

8 servings per container

Serving size 2/3 cup (55g)

Amount per 2/3 cup	
Calories	**230**
% DV*	
12%	**Total Fat** 8g
5%	Saturated Fat 1g
	Trans Fat 0g
0%	**Cholesterol** 0mg
7%	**Sodium** 160mg
12%	**Total Carbs** 37g
14%	Dietary Fiber 4g
	Sugars 1g
	Added Sugars 0g
	Protein 3g
10%	**Vitamin D** 2mcg
20%	**Calcium** 260mg
45%	**Iron** 8mg
5%	**Potassium** 235mg

* Footnote on Daily Values (DV) and calories reference to be inserted here.

Figure 1.7. Nutrition Facts

When you look at the Nutrition Facts panel on a food label, you'll see that it lists calories, as well as grams of total fat, total carbohydrates, and protein per serving. From these values, you can estimate the amount of calories coming from the different macronutrients.

Looking at the values in the Nutrition Facts label, you can convert grams into calories by doing the following calculations:

- 8 grams of fat x 9 kcal/g = 72 kcals
- 37 grams of carbohydrate x 4 kcal/g = 148 kcals
- 3 grams of protein x 4 kcal/g = 12 kcals

You can double check your math by adding the calories per serving provided from fat, carbohydrate, and protein (232 calories for the example above). This number should come close to the total calories per serving listed on the Nutrition Facts. It will not always match up exactly (like in the example above) due to rounding.

Organic and Inorganic Nutrients

So far, we've categorized nutrients as macronutrients or micronutrients and based on whether or not they're energy-yielding. There is one more way to categorize nutrients: organic or inorganic. When you think of the word "organic," you might think of how foods are produced (with or without synthetic fertilizers and pesticides), but in this case we are referring to the chemical structure of a nutrient.

Organic Nutrients

The organic nutrients include the macronutrients (carbohydrate, protein, and fat) and vitamins. An ***organic*** nutrient contains both carbon and hydrogen. Organic nutrients can be made by living organisms and are complex, made up of many elements (carbon, hydrogen, oxygen, and sometimes nitrogen) bonded together. In a sense, they are "alive," and therefore can be destroyed or broken down.

Vitamin E (shown below) is an organic molecule, because it contains both carbon and hydrogen atoms. Vitamin E is synthesized by plants and can be destroyed by heat during cooking.

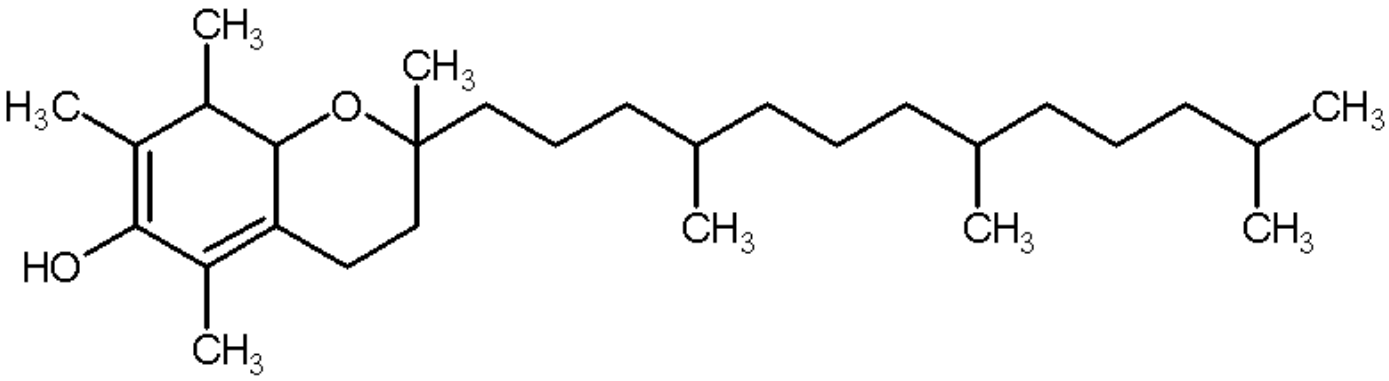


Figure 1.8. Chemical structure of Vitamin E

Inorganic Nutrients

Inorganic nutrients include both water and minerals. ***Inorganic*** nutrients do not contain both carbon and hydrogen, and they are not created or destroyed. Minerals can't be destroyed, so they are the ash left when a food is burned to completion. Minerals are also not digested or broken down, as they are already in their simplest form. They are absorbed as-is, then shuttled around the body for their different functions, and then excreted.

Summary

The different categories of nutrients are summarized in the following table.

Classification	**Nutrient**
Macronutrient	Carbohydrate, protein, lipids, water
Micronutrient	Vitamins, minerals
Energy-Yielding	Carbohydrate, protein, fat
Organic	Carbohydrate, protein, lipids, vitamins
Inorganic	Minerals, water

Table 1.3. Summary of nutrient classifications

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3.1.4: Defining Nutrient Requirements — Dietary Reference Intakes

Learning Objectives

Describe the Dietary Reference Intakes and explain how they may be used.

How do we know how much of a given nutrient people should eat, or how much is too much? For this information, we can turn to the ***Dietary Reference Intakes (DRI)*** — a set of recommendations developed by the National Academies of Sciences, Engineering, and Medicine to describe the amounts of specific nutrients and energy that people should consume in order to stay healthy. They are developed by groups of nutrition scientists, who together evaluate the research to determine how much of a nutrient is required to prevent deficiencies and chronic disease, as well as how much is excessive and could cause toxicity. The DRI standards are specific to people living in the United States and Canada, and they're meant to be used by people who are generally healthy, because those with specific health conditions may have different nutrient requirements.

The DRI standards can be divided into two main categories:

- **Recommendations for energy intake** – How many calories are required, and how much energy should proportionately come from carbohydrate, fat, and protein?
- **Recommendations for nutrient intake** – How much of each nutrient should be consumed, and how much is excessive?

We'll discuss each of these categories, and then we'll discuss some of the ways that the DRI standards are used. Be prepared to learn a lot of acronyms!

DRI Recommendations for Energy Intake

The DRIs include two types of recommendations related to energy intake: Estimated Energy Requirement (EER), and Acceptable Macronutrient Distribution Ranges (AMDRs).

Estimated Energy Requirement (EER)

Estimated Energy Requirement (EER): The average dietary energy intake that is predicted to maintain energy balance in a healthy adult of a defined age, gender, weight, height, and level of physical activity consistent with good health.[3]

The EER is an estimate of how many calories a person needs to consume, on average, each day to stay healthy, based on their age, sex, height, weight, and physical activity level. For adults, the EER is meant to be a caloric intake that maintains energy balance, meaning that it won't cause weight loss or gain. For children, the EER includes the energy needed for normal growth. For pregnant or lactating women, it includes energy needed for development of the fetus and other pregnancy requirements or for milk production. Different EER values were also developed for different physical activity levels, because greater physical activity requires more energy.[1] To see the different equations used for these populations, select the population(s) of interest from the Canadian Government's Equations to Estimate Energy Requirement website. To calculate your own EER, you'll need to input your weight in kilograms (kg) and your height in centimeters (cm). The EER should be considered a "ballpark" estimate of a person's caloric needs. As we'll learn later in the term, the way that people process and utilize energy is highly variable, and two people can have the same sex, weight, height, and level of physical activity but different caloric needs.

Acceptable Macronutrient Distribution Ranges (AMDRs)

Acceptable Macronutrient Distribution Ranges (AMDRs): Ranges of macronutrient intakes that are associated with reduced risk of chronic disease, while providing recommended intakes of other essential nutrients.[3]

The AMDR is the calculated range of how much energy from carbohydrate, fat, and protein is recommended for a healthy

diet. The AMDRs are as follows: Carbohydrate 45-65%, Fat 20-35%, and Protein 10-35%. People who do not meet the AMDR may have increased risk of developing health complications—although these are also ballpark recommendations, not absolute requirements for health. Keep in mind that the percentage of daily caloric intake from the three energy-yielding macronutrients will add up to 100 percent, so the proportion of each influences the other two. For example, someone consuming a very low carbohydrate diet, with just 5 to 10 percent of calories coming from carbohydrates would not only fall short of the AMDR for carbohydrate but also exceed the recommended amounts of fat and/or protein, because the rest of daily calories must come from these macronutrients. The AMDR recommendations are based on balancing carbohydrate, fat, and protein to allow for adequate amounts of all three, and they are wide enough ranges that many different types of diets can fit within them.

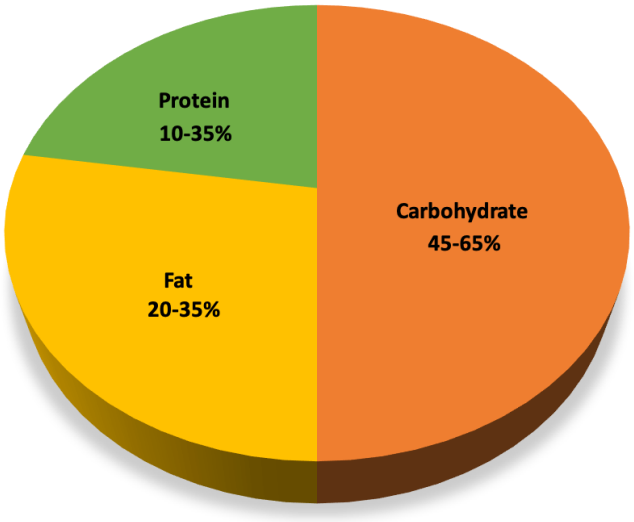


Figure 3.1.4.1: Acceptable Macronutrient Distribution Ranges (AMDR) for the three energy-yielding macronutrients. “Acceptable Macronutrient Distribution Ranges (AMDR)” by Alice Callahan is licensed under CC BY 4.0.

Daily Recommendations for Nutrient Intake

There are four different types of DRI values used to describe recommendations for intake of individual nutrients:

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

DRI values are summarized in tables to make it easy to find a specific value for a person based on their life stage and sex. For example, part of a table of EAR values for macronutrients and vitamins is shown below.

Dietary Reference Intakes (DRIs): Estimated Average Requirements
Food and Nutrition Board, Institute of Medicine, National Academies

Life Stage Group	CHO (g/d)	Protein (g/kg/d)	Vit A (µg/d)[a]	Vit C (mg/d)	Vit E (mg/d)[b]	Thiamin (mg/d)	Ribo-flavin (mg/d)	Niacin (mg/d)[c]	Vit B_6 (mg/d)
Infants									
7–12 mo		1.0							
Children									
1–3 y	100	0.87	210	13	5	0.4	0.4	5	0.4
4–8 y	100	0.76	275	22	6	0.5	0.5	6	0.5
Males									
9–13 y	100	0.76	445	39	9	0.7	0.8	9	0.8
14–18 y	100	0.73	630	63	12	1.0	1.1	12	1.1
19–30 y	100	0.66	625	75	12	1.0	1.1	12	1.1
31–50 y	100	0.66	625	75	12	1.0	1.1	12	1.1
51–70 y	100	0.66	625	75	12	1.0	1.1	12	1.4
> 70 y	100	0.66	625	75	12	1.0	1.1	12	1.4
Females									
9–13 y	100	0.76	420	39	9	0.7	0.8	9	0.8
14–18 y	100	0.71	485	56	12	0.9	0.9	11	1.0
19–30 y	100	0.66	500	60	12	0.9	0.9	11	1.1
31–50 y	100	0.66	500	60	12	0.9	0.9	11	1.1
51–70 y	100	0.66	500	60	12	0.9	0.9	11	1.3
> 70 y	100	0.66	500	60	12	0.9	0.9	11	1.3
Pregnancy									
14–18 y	135	0.88	530	66	12	1.2	1.2	14	1.6
19–30 y	135	0.88	550	70	12	1.2	1.2	14	1.6
31–50 y	135	0.88	550	70	12	1.2	1.2	14	1.6
Lactation									
14–18 y	160	1.05	885	96	16	1.2	1.3	13	1.7
19–30 y	160	1.05	900	100	16	1.2	1.3	13	1.7
31–50 y	160	1.05	900	100	16	1.2	1.3	13	1.7

Table 3.1.4.1: This page from the National Institutes of Health Office of Dietary Supplements provides links to DRI reports and tables: Nutrient Recommendations: Dietary Reference Intakes (DRI)

Let's look at how each of these DRI values is determined, what they mean, and how they are used.

Estimated Average Requirement

Estimated Average Requirement (EAR): The average daily nutrient intake level estimated to meet the requirement of half the healthy individuals in a particular life stage and gender group.[3]

The *Estimated Average Requirement (EAR)* is the amount of a nutrient that meets the requirements of 50 percent of people within a group of the same life stage and sex. The requirements of half of the group will fall below the EAR, and the requirements of the other half will be above it. To understand the EAR, it's important to recognize that individuals have different nutrient requirements, depending on many factors beyond our life stage and sex (differences in genetics, metabolism, body weight, and physical activity, for example), and the EAR is like the midpoint in the range of different individual requirements.

To develop the EAR, a committee of scientists evaluates the research on that nutrient and chooses a specific bodily function as a criterion on which to base it. For example, the EAR for calcium is set using a criterion of maximizing bone health, because this is quantitatively one of the most important functions of calcium, and the effects of different levels of calcium intake on bone health can be measured. 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.

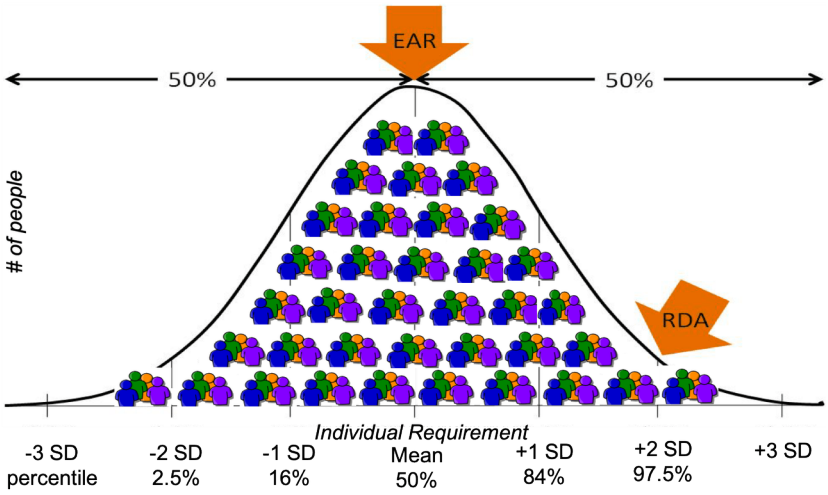


Figure 3.1.4.2: EAR and RDA relative to individual requirements for a given nutrient.

"EAR and RDA relative to individual requirements for a given nutrient" by Alice Callahan is licensed under CC BY 4.0; edited from "Fig 8.43, Kansas State University Human Nutrition Flexbook" by Brian Lindshield is licensed under CC BY-NC-SA 4.0, with the addition of "small people 7 clip art" by Public Domain Clip Art in the Public Domain.

Recommended Dietary Allowances

Recommended Daily Allowance (RDA): The average daily dietary nutrient intake level sufficient to meet the nutrient requirement of nearly all (97 to 98 percent) healthy individuals in a particular life stage and gender group.[3]

Once the EAR of a nutrient has been established, the RDA value can be mathematically determined. While the EAR is set at a point that meets the needs of half the population, **RDA values are set to meet the needs of the vast majority (97 to 98 percent) of the target healthy population**. You can see this in the graph above. The RDA is a better recommendation for the population, because we can assume that if a person is consuming the RDA of a given nutrient, they are most likely meeting their nutritional needs for that nutrient.

This also explains why the RDA is not the same thing as an individual nutritional requirement. You may be consuming less than the RDA for calcium, but this does not automatically mean that your body is deficient in calcium and that you'll definitely end up with osteoporosis, because your *individual* calcium requirement may be less than the RDA. However, since you probably don't know your individual calcium requirement, the RDA is a good target amount for consumption, and the more your intake drops below the RDA, the greater your risk of later developing osteoporosis. 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.

It's interesting to compare and contrast the EER (for energy or calorie intake) and the RDA (for nutrient intake). In practice, both types of recommendations serve as a daily target for intake. However, the EER is set to meet the average caloric needs of a person, while the RDA is set to meet the needs of the vast majority of the population. Imagine if the EER was set to ensure that it met the caloric needs of the vast majority of a population. It would end up being a dramatic overestimate of caloric needs for most people. If everyone actually followed this recommendation, the majority of them would consume far more calories than they actually needed, resulting in weight gain. For nutrients, we have more flexibility in our intake, because we have ways of storing or metabolizing and excreting excess nutrients, so consuming somewhat more than our body needs is just fine.

Adequate Intake

Adequate Intake (AI): The recommended average daily intake level based on observed or experimentally determined approximations or estimates of nutrient intake by a group (or groups) of apparently healthy people that are assumed to be adequate—used when an RDA cannot be determined.[3]

When there is insufficient scientific evidence to set an EAR and RDA for the entire population, then the National Academies committee can decide to set an Adequate Intake (AI) level instead. **The AI is based on observing healthy people and seeing how much of the nutrient in question they are consuming**. An AI is less precise than an RDA, but in the absence of an RDA, the AI is our best guess of how much of a given nutrient is needed. If there is not an RDA for a nutrient, than the AI is used as the nutrient-intake goal.

For example, there has not been sufficient scientific research into the exact nutritional requirements for infants. Consequently, all of the DRI values for infants are AIs derived from nutrient values in human breast milk. For older babies and young children, AI values are derived from human milk coupled with data on adults. The AI is meant for a healthy target group and is not meant to be sufficient for certain at-risk groups, such as premature infants.

Tolerable Upper Intake Level

Tolerable Upper Intake Level (UL): The highest average daily nutrient intake level that is likely to pose no risk of adverse health effects to almost all individuals in the general population. As intake increases above the UL, the potential risk of adverse effects may increase.[3]

It's rare to find amounts of a nutrient exceeding the UL in a balanced diet based on whole foods. However, a person who consumes dietary supplements, foods fortified with high levels of additional nutrients (protein bars, for example) or a diet based on only a few foods, might exceed the UL, and this could cause problems with nutrient toxicity. If you're selecting a supplement, be sure to choose one that does not exceed the UL for any nutrient, unless this is under specific instructions from your doctor or a Registered Dietitian.

When a nutrient does not have any *known* issue if taken in excessive doses, it is not assigned a UL. However, if a nutrient does not have a UL, that doesn't necessarily mean that it is safe to consume in large amounts—only that there isn't currently evidence that large amounts will cause problems. Science is an ongoing process, and the toxicity of many nutrients hasn't yet been studied.

Putting It All Together

The graph below summarizes the meaning of the four DRI values for nutrient intake.

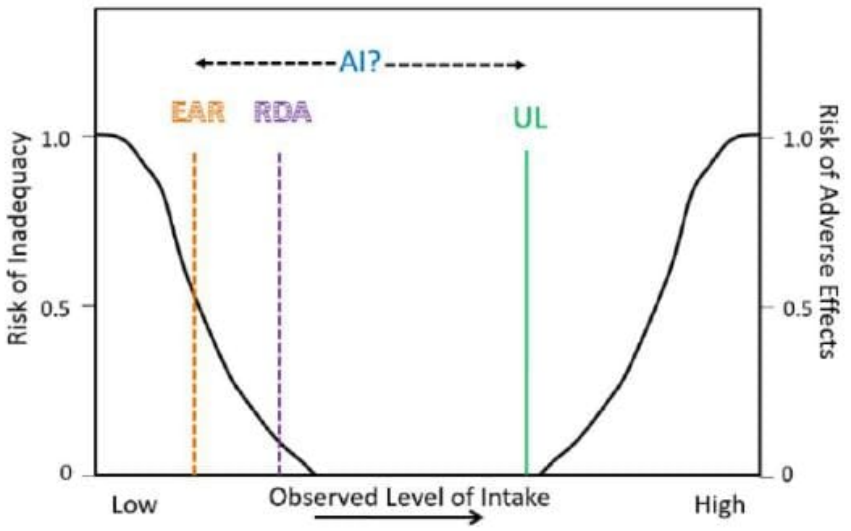


Figure 3.1.4.3: DRI values for nutrient intake. The EAR, RDA, AI, and UL are shown relative to the observed level of intake and risk of inadequacy and adverse effects. "DRI values for nutrient intake." Kansas State University Human Nutrition Flexbook by Brian Lindshield is licensed under CC BY-NC-SA 4.0

This graph shows the risks of nutrient inadequacy and nutrient excess as we move from a low intake of a nutrient to a high intake. Starting on the left side of the graph, you can see that when you have a very low intake of a nutrient, your risk of nutrient deficiency is high. As your nutrient intake increases, the chances that you will be deficient in that nutrient decrease. The point at which 50 percent of the population meets their nutrient 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. The AI is shown to exist somewhere between the EAR and UL, as it's an amount of the nutrient known to maintain health.

Note that there is a wide margin between the RDA and UL, showing that a person might safely eat much more than the RDA for a given nutrient without concerns of nutrient toxicity. However, be aware that the margin of safety varies depending on the nutrient. For example, fat-soluble vitamins have a smaller margin of safety between the RDA and the UL than water-soluble vitamins, meaning that it's easier to consume toxic levels of fat-soluble vitamins.

YouTube Video

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

View this YouTube Video online

VIDEO: "Dietary Reference Intakes," Maurie Luetkemeier (September 16, 2015), 7 minutes. This video reviews the different types of DRI values and what they mean.

How the DRIs are used

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

The DRIs are also used by professionals, government agencies, and the food industry. Here are some examples of their applications[2]:

- **Health professionals**. Registered dietitians and other nutrition professionals use the DRIs to provide dietary counseling and education and to plan menus for institutions, such as hospitals, long-term care, prisons.
- **Development of dietary guidelines**. These include the U.S. Dietary Guidelines for Americans, MyPlate, and Canada's Food Guide. In each case, developers ensure that their advice will help people meet the DRI standards.
- **Nutrition labeling**. The DRIs help to inform Nutrition Facts labels on foods and Supplement Facts on supplement labels.
- **Assistance programs**. School meals, WIC, SNAP, Child and Adult Care, and Administration on Aging programs must ensure that their programs align with the DRI.
- **Nutrition monitoring research**. Data from surveys of what people in the U.S. and Canada eat are compared with the DRIs to monitor national nutritional health.
- **Military.** The military uses the DRIs as a reference to ensure nutrient needs are met for the armed forces, to plan meals, and to procure military rations.
- **Food and supplement industries**. In the development of healthy food and safe supplement products, these industries should refer to the DRI.

Application of the DRIs to Transgender and Gender-diverse Individuals

When developing nutrition guidelines for transgender and gender-diverse people, it is essential to tailor energy and nutrient recommendations with attention to their hormone status, transition timeline, and body composition changes rather than rigidly applying male vs female reference values. Many traditional equations for estimating energy needs (e.g. basal metabolic rate or total energy expenditure formulas) require a binary sex input; in practice, dietitians may choose to use sex assigned at birth, the affirmed gender, and use both male and female variables to calculate a range and express it as such, and then adjust based on

clinical response and lean mass changes. Because sex-based DRIs differ for iron, calcium, and sometimes protein, the clinician must interpret those in light of menstrual status, hormone therapy, and individual variation.

In sum, nutrition guidance for transgender individuals should be gender-affirming, individualized, and dynamic, with careful use of multiple assessment domains rather than overreliance on any single “reference” value.

YouTube Video

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

View this YouTube Video online

Video: Nutrition Assessment for Transgender and Gender-Diverse Patients hat’s in a Number? by **Dietitians in Nutrition Support** YouTube (May 27, 2025), 20:21. Join Dr. Jennifer Waters and Dr. Whitney Linsenmeyer as they share about best practices for conducting a nutrition assessment with patients or clients who identify as transgender or gender-diverse. They will share about gender-affirming communication as well as gender-affirming treatments, including hormone regimens and their impact on biochemical markers.

Attributions:

- University of Hawai‘i at Mānoa Food Science and Human Nutrition Program, “Understand Daily Reference Intakes,” CC BY-NC 4.0.

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3.1.5: Dietary Guidelines for Americans

Dietary Guidelines for Americans

The Dietary Guidelines are published and revised every five years jointly by the U.S. Department of Agriculture (USDA) and Health and Human Services (HHS) as a guide to healthy eating for Americans.

Purpose

The Dietary Guidelines are in place to give Americans, ages 2 and older, evidence-based information on what and how much to eat to stay healthy. These recommendations aim to:

- Promote health
- Prevent chronic disease
- Help people reach and maintain a healthy weight

Public health agencies, health care providers, and educational institutions all rely on Dietary Guidelines recommendations and strategies.[3] These agencies use the Dietary Guidelines to:

- Form the basis of federal nutrition policy and programs such as WIC and SNAP
- Help guide local, state, and national health promotion and disease prevention initiatives
- Inform various organizations and industries (for example products developed and marketed by the food and beverage industry)

Process

Before HHS and the USDA release the new Dietary Guidelines, they assemble an Advisory Committee. This committee is comprised of nationally recognized nutrition and medical researchers, academics, and practitioners. The Advisory Committee develops an Advisory Report that synthesizes current scientific and medical evidence in nutrition, which will then advise the federal government in the development of the new edition of the Dietary Guidelines.

The public also has opportunities to get involved in the development of these guidelines. The Advisory Committee holds a series of public meetings for hearing oral comments from the public, and the public also has opportunities to provide written comments to the Advisory Committee throughout the course of its work. After the Advisory Report is complete, the public has opportunities to respond with written comments on health.gov/dietaryguidelines and provide oral testimony at a public meeting.

2025–2030 Dietary Guidelines for Americans

The **Dietary Guidelines for Americans 2025–2030** represent a substantial shift in federal nutrition policy, framed around the directive to **“eat real food”** and to prioritize *whole, nutrient-dense foods* while sharply reducing reliance on *highly processed foods* laden with added sugars, refined carbohydrates, and chemical additives. These Guidelines recommend a **reimagined dietary framework** in which **protein, dairy, 'healthy' fats, vegetables, and fruits** take prominence, supported by specific intake goals (e.g., protein targets based on body weight and defined servings of fruits/vegetables), and *whole grains* play a comparatively smaller role at the base of the dietary model. The guidance also introduces explicit recommendations to support *gut health* through diverse, fiber-rich foods and fermented foods, and to avoid artificial flavors, preservatives, and low-calorie non-nutritive sweeteners. The approach continues to advocate limiting sodium and other risk factors but recalibrates how these are framed in the context of overall dietary patterns.

Key differences from the **2020–2025 Dietary Guidelines for Americans** include:

- **Protein emphasis and quantified intake:** The 2025–2030 Guidelines elevate protein as a central dietary priority, recommending **1.2–1.6 grams of protein per kilogram of body weight per day**, and encouraging protein at every meal from both animal- and plant-source foods — an explicit, individualized target absent from the prior edition.

- **Revised food hierarchy and visual model:** The traditional carbohydrate-centric model reflected in MyPlate and previous food pyramids gives way to a new inverted pyramid with *protein, dairy, fats, vegetables, and fruits* at the top and *whole grains* at the bottom — a conceptual reversal from the grain-focused base in 2020–2025.

- **Highly processed foods:** The 2025–2030 Guidelines go beyond general limits on added sugars and unhealthy fats by **explicitly urging avoidance of "highly processed" foods** such as packaged, prepared, ready-to-eat items with added sugars and sodium, and discouraging artificial additives — language that is more direct than in the 2020–2025 edition.

- **Added sugar framing:** Whereas the 2020–2025 Guidelines recommend limiting added sugars to *<10% of total calories*, the new edition states that **no amount of added sugars is considered part of a healthy diet**, suggesting a per-meal cap of roughly 10 g if consumed.

- **Alcohol guidance:** The previous Guidelines suggested specific limits on alcohol (up to one drink per day for women and two for men as part of moderation). In contrast, the 2025–2030 edition **removes specific drink limits**, instead advising general reduction for better health outcomes.

- **Saturated fat and dairy:** Although both editions maintain a recommendation to keep saturated fat below about 10% of calories, the 2025–2030 Guidelines incorporate **full-fat dairy and a broader acceptance of saturated fat from whole food sources** more explicitly — and pair them with nutrient-dense eating patterns — whereas 2020–2025 emphasized *low-fat* dairy as part of limiting saturated fat.

Collectively, the 2025–2030 Guidelines signify a **thematic reset** — articulating a nutrition philosophy that places *real, minimally processed foods* and *higher protein diets* at the center of healthy eating, expands explicit avoidance of processed and additive-laden foods, and adjusts framing on alcohol and fats. This contrasts with the **2020–2025 edition's emphasis on balanced nutrient-dense food groups, limiting saturated fat, added sugars, and alcohol in broad quantitative terms, and supporting a variety of healthy dietary patterns without individualized protein thresholds.**

Table: Key Differences Between DGA 2020–2025 and DGA 2025–2030

Category	DGA 2020–2025	DGA 2025–2030
Overall Framework	Emphasis on balanced dietary patterns and moderation	Emphasis on "eat real food" and food quality
Dietary Model	MyPlate-style model with strong emphasis on whole grains	Inverted pyramid emphasizing protein, dairy, fats, vegetables, and fruits; grains de-emphasized
Protein Guidance	No individualized targets; general encouragement of variety	Explicit protein intake recommendations based on body weight (approx. 1.2–1.6 g/kg/day)
Highly Processed Foods	General limits on added sugars, sodium, and saturated fat	Explicit recommendation to avoid highly processed foods and artificial additives
Added Sugars	Limit to <10% of total daily calories	States no amount is necessary for health; discourages routine consumption
Fats and Dairy	Emphasis on low-fat dairy and limiting saturated fat	Broader acceptance of full-fat dairy and saturated fat from whole food sources
Gut Health	Fiber emphasized primarily through whole grains	Expanded focus on fiber diversity, fermented foods, and gut microbiome health
Alcohol	Specific daily limits by sex (moderation framework)	Removal of numeric limits; general recommendation to reduce intake
Dietary Philosophy	Nutrient-focused, pattern-based moderation	Whole-food-centered, protein-forward, minimally processed eating

The Table above illustrates the conceptual shift in federal nutrition guidance from the 2020–2025 Dietary Guidelines for Americans, which emphasize balanced dietary patterns with whole grains as a foundational component, toward the 2025–2030 Guidelines, which prioritize whole, minimally processed foods and place greater emphasis on protein, dairy, 'healthy' fats,

vegetables, and fruits. The updated framework de-emphasizes refined and highly processed foods, introduces individualized protein intake guidance, and reflects a broader transition from nutrient-based moderation to food-quality–driven dietary patterns.



Figure 3.1.5.2: Inverted Dietary Pyramid Emphasizing Whole, Minimally Processed Foods in the Dietary Guidelines for Americans 2025–2030

2020-2025 Dietary Guidelines for Americans

1. Follow a healthy dietary pattern at every life stage.

At every life stage—infancy, toddlerhood, childhood, adolescence, adulthood, pregnancy, lactation, and older adulthood—it is never too early or too late to eat healthfully.

- **For about the first 6 months of life**, exclusively feed infants human milk. Continue to feed infants human milk through at least the first year of life, and longer if desired. Feed infants iron-fortified infant formula during the first year of life when human milk is unavailable. Provide infants with supplemental vitamin D beginning soon after birth.
- **At about 6 months**, introduce infants to nutrient-dense complementary foods. Introduce infants to potentially allergenic foods along with other complementary foods. Encourage infants and toddlers to consume a variety of foods from all food groups. Include foods rich in iron and zinc, particularly for infants fed human milk.
- **From 12 months through older adulthood**, follow a healthy dietary pattern across the lifespan to meet nutrient needs, help achieve a healthy body weight, and reduce the risk of chronic disease.

2. Customize and enjoy nutrient-dense food and beverage choices to reflect personal preferences, cultural traditions, and budgetary considerations.

A healthy dietary pattern can benefit all individuals regardless of age, race, or ethnicity, or current health status. The Dietary Guidelines provides a framework intended to be customized to individual needs and preferences, as well as the foodways of the diverse cultures in the United States.

3. Focus on meeting food group needs with nutrient-dense foods and beverages, and stay within calorie limits.

An underlying premise of the Dietary Guidelines is that nutritional needs should be met primarily from foods and beverages—specifically, nutrient-dense foods and beverages. Nutrient-dense foods provide vitamins, minerals, and other health-promoting components and have no or little added sugars, saturated fat, and sodium. A healthy dietary pattern consists of

nutrient-dense forms of foods and beverages across all food groups, in recommended amounts, and within calorie limits. The core elements that make up a healthy dietary pattern include:

- **Vegetables of all types**—dark green; red and orange; beans, peas, and lentils; starchy; and other vegetables
- **Fruits**, especially whole fruit
- **Grains**, at least half of which are whole grain
- **Dairy**, including fat-free or low-fat milk, yogurt, and cheese, and/or lactose-free versions and fortified soy beverages and yogurt as alternatives
- **Protein foods**, including lean meats, poultry, and eggs; seafood; beans, peas, and lentils; and nuts, seeds, and soy products
- **Oils**, including vegetable oils and oils in food, such as seafood and nuts

4. Limit foods and beverages higher in added sugars, saturated fat, and sodium, and limit alcoholic beverages.

At every life stage, meeting food group recommendations—even with nutrient-dense choices—requires most of a person's daily calorie needs and sodium limits. A healthy dietary pattern doesn't have much room for extra added sugars, saturated fat, or sodium—or for alcoholic beverages. A small amount of added sugars, saturated fat, or sodium can be added to nutrient-dense foods and beverages to help meet food group recommendations, but foods and beverages high in these components should be limited. Limits are:

- **Added sugars**—Less than 10 percent of calories per day starting at age 2. Avoid foods and beverages with added sugars for those younger than age 2.
- **Saturated fat**—Less than 10 percent of calories per day starting at age 2.
- **Sodium**—Less than 2,300 milligrams per day—and even less for children younger than age 14.
- **Alcoholic beverages**—Adults of legal drinking age can choose not to drink, or to drink in moderation by limiting intake to 2 drinks or less in a day for men and 1 drink or less in a day for women, when alcohol is consumed. Drinking less is better for health than drinking more. There are some adults who should not drink alcohol, such as women who are pregnant.



Figure 3.1.5.1: "Fresh Berries" by Cookbookman17 is licensed under CC BY 2.0

Many Americans fall below the EAR and AI for fiber, calcium, potassium, magnesium, choline, and vitamins A, D, E and C.[1] One aim of the Dietary Guidelines is to help Americans increase their intake of foods that contain these key nutrients—vegetables, fruits, whole grains, and dairy.

The United States is not the only country that develops nutritional guidelines.
The Food and Agriculture Organization of the United Nations has a website where you can search for dietary guidelines for different countries, such as Sweden's guidelines, illustrated below.



Figure 3.1.5.2: "Sweden's one-minute advice" by Food and Agriculture Organization of the United Nations (FAO) is licensed under CC BY 3.0

" *Sweden's one-minute advice* " *by Food and Agriculture Organization of the United Nations (FAO)*

The Swedish National Food Agency also has a great resource, "Find Your Way To Eat Greener, Not Too Much and Be Active" on how to put these guidelines into practice.MyPlate (USDA Food Guide)

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- "Recommendations for Optimal Heath," section 2.5 from the book An Introduction to Nutrition (v. 1.0), CC BY-NC-SA 3.0

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3.1.6: MyPlate, DASH, and The Mediterranean Diet

MyPlate (USDA Food Guide)

One way the USDA and other federal agencies implement the Dietary Guidelines is through MyPlate — a food guide to help Americans achieve the goals of the Dietary Guidelines for Americans.

Image 3.1.6.1: "MyPlate pictogram" by USDA is licensed under CC BY 2.0

In practice, this means eating a combination of foods from the different food groups, in adequate quantities, in the right proportions relative to each other. Because these food groups provide different nutrients, following MyPlate recommendations is likely to support adequate nutrient intake. For example, vegetables are an important source of potassium, dietary fiber, folate, vitamin A, and vitamin C, whereas grains provide B vitamins (thiamin, riboflavin, niacin, and folate) and minerals (iron, magnesium, and selenium). No one food or food group is more important than the other. It is the combination of all the different food groups — fruit, vegetables, grains, dairy, & protein foods — that will ensure an adequate diet.

Historical Background

For many years, the U.S. government has been encouraging Americans to develop healthful dietary habits. The USDA's food guidance system has evolved over the decades — from the Basic Four in the 1950s to the Food Pyramid in 1992 — culminating in the launch of MyPlate in 2011, a simplified, plate-shaped pictogram designed to help Americans make healthier, more varied food choices at a glance.

The Food Pyramids

The food pyramid was introduced in 1992 as the symbol of healthy eating patterns for all Americans.

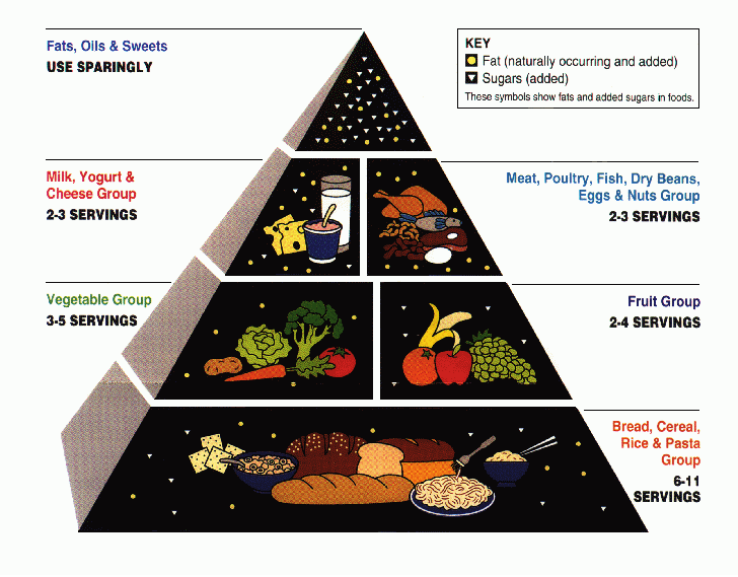


Figure : "The original food pyramid" from the USDA is in the Public Domain

In 2005, the food pyramid was replaced with MyPyramid.

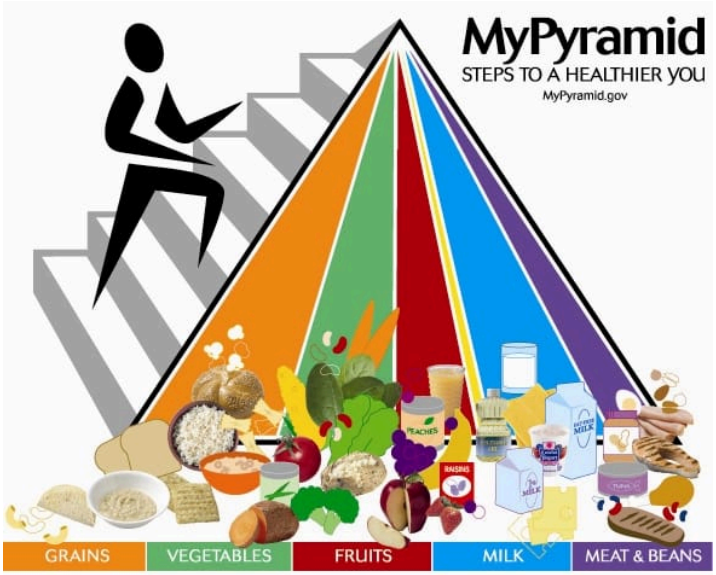


Figure : “Mypyramid” from the USDA is in the Public Domain

MyPyramid, introduced in 2005.

However, many felt this new pyramid was difficult to understand, so in 2011, the pyramid was replaced with MyPlate.

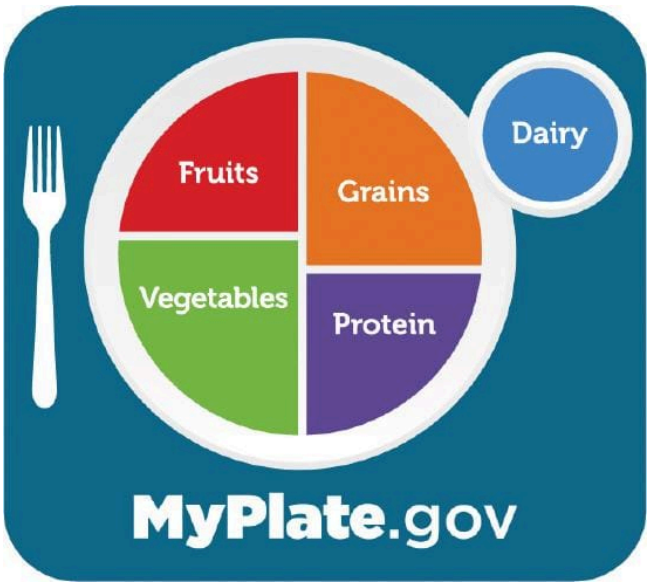


Figure : “MyPlate” from the USDA is in the Public Domain

MyPlate is a food guide to help Americans achieve the goals of the Dietary Guidelines for Americans. For most people this means eating **MORE**:

- whole grains
- fruits
- vegetables (especially dark green vegetables and red and orange vegetables)
- legumes
- seafood (to replace some meals of meat and poultry)
- low-fat dairy

And **LESS**:

- refined grains

- added sugars
- solid fats: saturated fats, trans fats, and cholesterol
- sodium

Foods are grouped into 5 different groups based on their nutrient content. The following table summarizes the different food groups, examples of foods that fall within each group, and nutrients provided for each food group.

Food Group	Examples of Foods	Nutrients Provided
	**Whole grains**: brown rice, oats, whole wheat bread, cereal and pasta, popcorn **Refined grains**: typically tortillas, couscous, noodles, naan, pancakes (although sometimes these products can be whole grains too) For more foods and what counts as a cup check out: The Grain Group Food Gallery	• dietary fiber • several B vitamins (thiamin, riboflavin, niacin, and folate) • minerals (iron, magnesium, and selenium)
	**Dark green vegetables**: broccoli, kale, and spinach **Red and orange vegetables**: bell peppers, carrots and tomatoes **Starchy vegetables**: corn, peas and potatoes **Beans and Peas**: hummus, lentils and black beans **Other vegetables**: asparagus, avocado, zucchini For more foods and what counts as a cup check out: The Vegetable Group Food Gallery	• potassium • dietary fiber • folate • vitamin A • vitamin C
	Fresh berries, melons, and other fruit as well as 100% fruit juice Fruits can also be canned, frozen, or dried, and may be whole, cut-up, or pureed For more foods and what counts as a cup check out: The Fruit Group Food Gallery	• potassium • dietary fiber • vitamin C • folate
	Meats, poultry, seafood, beans and peas, eggs, nuts and seeds For more foods and what counts as a cup check out: The Protein Group Food Gallery	• protein • B vitamins (niacin, thiamin, riboflavin, and B6) • vitamin E • iron • zinc • magnesium

	Milk, yogurt, cheese and calcium-fortified soy milk Foods such as cream cheese, cream, and butter, are not part of the Dairy Group as they have little/no calcium (they count as a fat) For more foods and what counts as a cup check out: The Dairy Group Food Gallery	• calcium • potassium • vitamin D • protein

Table 3.1.6.1: *A summary of MyPlate food groups, examples of foods that fall within each group, and nutrients provided for each food group.* "MyPlate Summary" by Tamberly Powell is licensed under CC BY-NC-SA 4.0; information in the table is from ChooseMyPlate is in the Public Domain "Food Group Buttons" from the USDA is in the Public Domain

This graphic summarizes serving sizes for each of the food groups:



Figure : "Cup- and ounce-equivalents" by the Dietary Guidelines for Americans, Figure 1.1, is in the Public Domain

Planning a healthy diet using the MyPlate approach is intended to be straightforward and easy-to-implement:

- **Fill half of your plate with a variety of fruits and vegetables**, including red, orange, and dark green vegetables and fruits, such as kale, collard greens, tomatoes, sweet potatoes, broccoli, apples, oranges, grapes, bananas, blueberries, and strawberries in main and side dishes. Vary your choices to get the benefit of as many different vegetables and fruits as you can. One hundred percent fruit juice is also an acceptable choice as long as only half your fruit intake is replaced with juice.
- Fill a quarter of your plate with grains. **Half of your daily grain intake should be whole grains such as 100 percent whole-grain cereals, breads, crackers, rice, and pasta.** Read the ingredients list on food labels carefully to determine if a food is comprised of whole grains. We will discuss how to identify whole grains in more detail in later units.
- **Select a variety of protein foods to improve nutrient intake and promote health benefits.** Each week, be sure to include a nice array of protein sources in your diet, such as nuts, seeds, beans, legumes, poultry, soy, and seafood. The recommended consumption amount for seafood for adults is two 4-ounce servings per week. When choosing meat, select lean cuts.



Figure : "Lentil Quinoa Soup" by Tasha is licensed under CC BY 2.0

- **If you enjoy drinking milk or eating dairy products, such as cheese and yogurt, choose low-fat or nonfat products.** Low-fat and nonfat products contain the same amount of calcium and other essential nutrients as whole-milk products, but with much less fat and calories. For this reason, MyPlate's Dairy Group ***does not include*** foods made from milk that have little calcium and a high fat content, such as cream cheese, sour cream, cream, and butter. Calcium, an important mineral for your body, is also found in lactose-free dairy products and fortified plant-based beverages, like soy milk. Fortified soy milk and yogurt are part of MyPlate's Dairy Group. You can also get calcium from vegetables and other fortified foods and beverages.
- Although not shown on the MyPlate pictogram, **oils are also an important component of a healthy diet** because they contain valuable essential fatty acids. Oils are lipids (fats) that are liquid at room temperature, like vegetable oils used in cooking. Oils include fats from many different plants and from fish that are liquid at room temperature, such as canola, corn, olive, soybean, and sunflower oil. Some foods are naturally high in oils, like nuts, olives, some fish, and avocados. Foods that are mainly oil include mayonnaise, certain salad dressings, and soft margarine. Although oils are essential for health, they do contain about 120 calories per tablespoon, so moderation is important.

Some people have criticized the Dietary Guidelines for Americans and MyPlate for being influenced by political and economic interests, as the meat and dairy industries and large food companies have a powerful lobbying presence. Marion Nestle, author of the book, "Food Politics: How the Food Industry Influences Nutrition and Health," gives her review of the guidelines and discusses a bit of the politics behind them in her blog post, "The 2015 Dietary Guidelines, at long last."

Another guide for creating healthy, balanced meals comes from Harvard's School of Public Health. The Healthy Eating Plate (HEP) is based on the best available science and is purported not to be influenced by political or commercial pressures from food industry lobbyists.

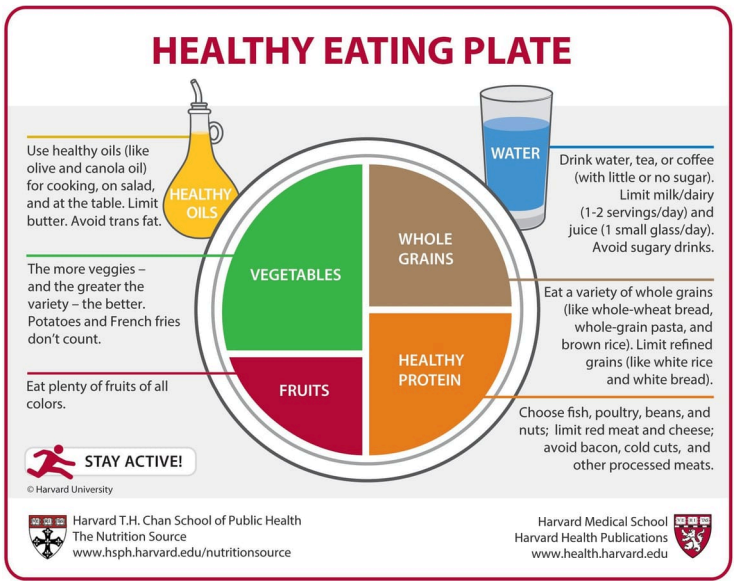


Figure : "Harvard's Healthy Eating Guide" Copyright © 2011, Harvard University. Health, www.thenutritionsource.org, and Harvard Health Publications, www.health.harvard.edu.

The message of the HEP is very similar to MyPlate in that the focus is on diet quality — encouraging nutrient-dense whole grains, fruits, vegetables, and beans. However, there are a few key differences between MyPlate and HEP. For example, although not shown on the MyPlate pictogram, oils, which are also an important component of a healthy diet, are shown on the HEP. Additionally, MyPlate recommends 3 cups of dairy a day, whereas HEP recommends limiting dairy to 1-2 cups per day, and instead encourages non-dairy sources of calcium like collards, bok choy, fortified soy milk, and baked beans.

The HEP encourages protein sources from fish, poultry, beans or nuts, and it encourages consumers to limit red meat and avoid processed meat (since these foods raise the risk of heart disease, diabetes, and colon cancer.)[5] MyPlate does not mention that red and processed meat should be limited. Why not? According to Marion Nestle, "Politics, of course."

DASH and The Mediterranean Diet

Both the DASH (Dietary Approaches to Stop Hypertension) and Mediterranean diets are evidence-based eating patterns that have been extensively studied and shown to improve overall health, particularly cardiovascular outcomes. Each has been presented earlier in this textbook, and in applying nutrition science to design a healthy diet, they serve as practical and effective models. The DASH diet offers specific numerical guidance — such as recommended daily servings of fruits, vegetables, grains, and low-fat dairy — making it straightforward for individuals seeking clear, quantifiable targets.

Table 1: Daily and Weekly Food Recommendations in the DASH Eating Plan (2,000 kcal/day)

Food Group / Component	Recommended Servings	Serving Examples	Frequency	Key Nutritional Emphasis
Grains (preferably whole)	6–8 servings	1 slice bread, ½ cup cooked rice/ pasta/cereal	Daily	Provides energy, fiber, B vitamins
Vegetables	4–5 servings	1 cup raw leafy vegetables, ½ cup cooked vegetables	Daily	Rich in potassium, magnesium, fiber
Fruits	4–5 servings	1 medium fruit, ½ cup fresh/ frozen/canned fruit	Daily	Provides potassium, fiber, antioxidants
Fat-free or Low-fat Dairy	2–3 servings	1 cup milk or yogurt, 1½ oz cheese	Daily	Calcium, protein, vitamin D

Food Group / Component	Recommended Servings	Serving Examples	Frequency	Key Nutritional Emphasis
Lean Meats, Poultry, and Fish	≤6 oz cooked (≈2 servings)	3 oz cooked meat, poultry, or fish	Daily	Protein, iron, zinc; limit saturated fat
Nuts, Seeds, and Legumes	4–5 servings	⅓ cup nuts, 2 Tbsp seeds, ½ cup cooked beans	Weekly	Magnesium, potassium, protein, fiber, healthy fats
Fats and Oils	2–3 servings	1 tsp soft margarine, 1 Tbsp mayonnaise, 2 Tbsp salad dressing	Daily	Encourages unsaturated fats, limits saturated fats
Sweets	≤5 servings	1 Tbsp sugar, jelly, or jam; ½ cup sorbet	Weekly	Limits added sugars and calories
Sodium	≤2,300 mg (standard DASH) or ≤1,500 mg (lower-sodium DASH)	—	Daily	Helps lower blood pressure



In contrast, the Mediterranean diet is more descriptive and less prescriptive, emphasizing an overall pattern of eating that includes abundant plant foods, olive oil as the primary fat, moderate consumption of fish and poultry, and limited intake of red meat and sweets.

Table 2. Key Foods and Frequency Emphasized in the Mediterranean Diet

Frequency	Food / Component	Description / Notes
Daily	**Vegetables**	Variety of colors and types; aim for several servings per day.
	Fruits	Fresh, seasonal fruits preferred for dessert and snacks.
	Whole grains	Whole-grain bread, pasta, rice, couscous, and other minimally processed grains.
	Olive oil	Primary source of added fat; used for cooking and dressings.
	Nuts and seeds	Small handful daily; include almonds, walnuts, pistachios, sunflower seeds, and others.
	Legumes	Beans, lentils, and peas as main protein sources in plant-based meals.
	Herbs and spices	Used liberally in place of salt to flavor foods.
	Moderate dairy	Mainly yogurt and cheese, often from sheep or goat milk.

Frequency	Food / Component	Description / Notes
	Water	Main beverage; red wine optional in moderation with meals (for adults who choose to drink).
Weekly	**Fish and seafood**	At least twice per week; rich in omega-3 fatty acids.
	Poultry and eggs	Moderate portions several times per week.
	Potatoes	In moderation, preferably boiled or baked rather than fried.
	Sweets and pastries	Limited; reserved for special occasions.
	Red meat	Small portions, less frequently — typically a few times per month or less.

For individuals looking for a sensible and sustainable place to begin improving their eating habits, either of these well-established eating patterns — DASH or Mediterranean — provides an excellent starting point. Both align closely with foods familiar to and enjoyed by many Americans, making them realistic and enjoyable frameworks for long-term dietary change.

Attributions:

Edit section

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- "Recommendations for Optimal Heath," section 2.5 from the book An Introduction to Nutrition (v. 1.0), CC BY-NC-SA 3.0

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Edit section

- [1]US Department of Health and Human Services and U.S. Department of Agriculture. (2020). Dietary Guidelines for Americans. Retrieved from https://www.dietaryguidelines.gov/sites/default/files/2020-12/DGA_2020-2025_ExecutiveSummary_English.pdf
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3.1.7: Reading and Understanding Nutrition Facts labels

Not so long ago, food choices were limited to what could be grown or raised, hunted or gathered. Today, grocery stores offer seemingly infinite choices in foods, with entire aisles dedicated to breakfast cereals and cases filled with a multitude of different yogurts. Faced with so many choices, how can we decide? Taste matters, of course. But if a healthy diet is your goal, so does nutrition. Food labels are our window into the nutritional value of a given food. Let's examine what we can learn from food labels and how reading them can help us make smart choices to contribute to a healthy diet.



The U.S. Food and Drug Administration (FDA) requires food manufacturers to accurately label foods so that consumers can be informed about their contents. There are 5 types of information required by the FDA on every food label, except for fresh produce and seafood[1,2]:

1. Statement of identity *(what type of food is it?)*
2. Net contents of the package *(how much is in there?)*
3. Name and address of manufacturer (*where was it produced?*)
4. Ingredients list *(what ingredients are included in the food?)*
5. Nutrition information (*what is the amount of nutrients included in a serving of food?*)

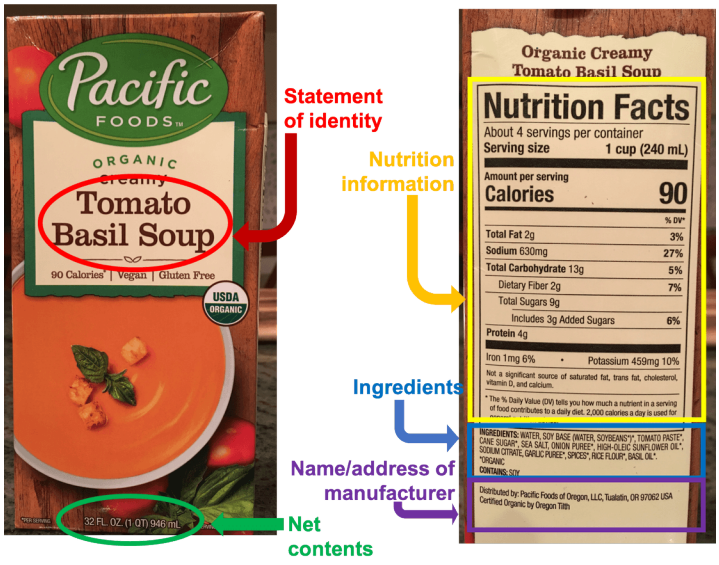


Figure 1.12. The 5 required types of information on a food label.

The statement of identity and net contents of the package tell you what type of food you're purchasing and how much is in the package. The name and address of the manufacturer are important if there's a food recall due to an outbreak of foodborne illness or other contamination issue. Given the size of our food system and the fact that one manufacturer may make products packaged under multiple brand names, being able to trace a food's origin is critical.

The last two types of required information—the ingredients list and the nutrition information—are a bit more complex and provide valuable information to consumers, so let's look more closely at each of these parts of a food label.

Ingredients List



The ingredients list includes all ingredients, **listed from most predominant to least predominant (by weight) in the product.** For example, in the corn muffin mix label to the right, the most prevalent ingredient is enriched unbleached flour (with ingredients in the flour then listed in parentheses), followed by sugar, cornmeal, salt, and then a few other ingredients.

This order of ingredients comes in handy when judging the nutritional value of a product. For example, in the ingredients list for the corn muffin mix shown at right, it's interesting to note that it contains more sugar than cornmeal! The ingredients list can also help you determine whether a bread contains more whole grain flour than refined flour. Or, if you're choosing a breakfast cereal and the first ingredient is sugar, that's a red flag that it's more of a dessert than part of a nutritious breakfast.

By law, food manufacturers must also list major allergens, which include milk, egg, fish, crustacean shellfish, tree nuts, wheat, peanuts, and soybeans.[2] Allergens may be listed in a separate statement, as on the corn muffin mix label, which lists "Contains: Wheat" on the label. Alternatively, allergens can be listed in parentheses within the ingredient list, such as "lecithin (soy)." Some labels include an optional "may contain" or "made in shared equipment with…" statement that lists additional allergens that could be present, not as ingredients in the food, but in trace amounts from equipment contamination. For people with food allergies, having this information clearly and accurately displayed on food packages is vital for their safety.

The Nutrition Facts Panel

If you want to learn about the nutritional value of a food, the Nutrition Facts panel is where you'll find this information. It's very useful for comparing products and for identifying foods that will be more or less valuable in meeting your nutritional goals. For example, if you're trying to watch your intake of added sugar or saturated fat, or you're trying to incorporate more dietary sources of calcium and vitamin D, the Nutrition Facts panel is a valuable tool. There are 4 main parts of a Nutrition Facts panel, shown in the figure below. The colors are added to highlight different sections of a label; Nutrition Facts are printed in black and white.

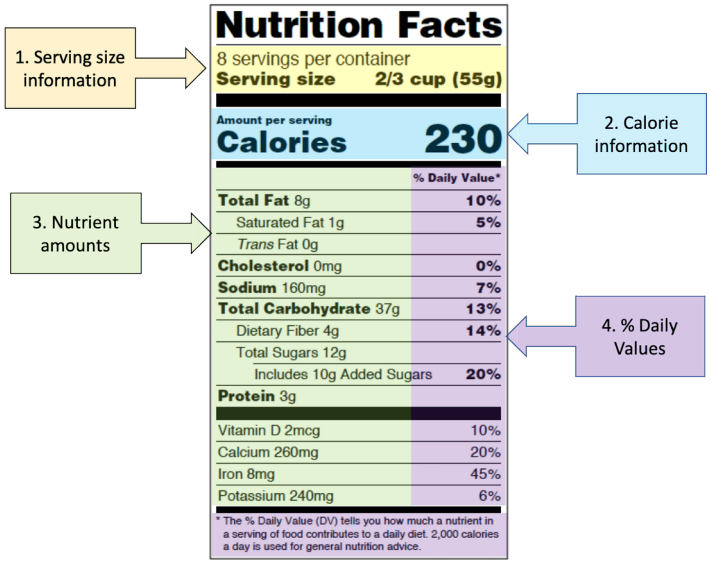


Figure 1.13. The four main sections of a Nutrition Facts label, highlighted in color.

1. Serving size information

It's fitting that serving size information is first on the Nutrition Facts panel, because all of the information that follows is based on it. **The serving size of the food is the amount that is customarily eaten at one time, and all of the nutrition information on the label is based on one serving of the food**. This section of the label also states the number of servings per container.[1]

It's important to note that you might not always eat one serving of a food; sometimes you might eat half of a serving, and sometimes you might eat two or more servings in one sitting. For example, if the label above is for a breakfast cereal, you might easily consume 1 ⅓ cups of cereal for breakfast. If you're interested in how many calories or nutrients you're consuming, you would need to double the nutrition values to accurately represent your breakfast, since the serving size is only ⅔ cup.

2. Calorie information

This section simply states the number of calories, or the amount of energy, provided in one serving of the food. Again, if you consume more or less than the serving size, you'll need to take that into consideration when estimating the calories you're consuming.

3. Nutrient amounts

The Nutrition Facts panel must list the amounts of these nutrients: total fat, saturated fat, trans fat, cholesterol, sodium, total carbohydrate, dietary fiber, sugars, added sugars, protein, calcium, vitamin D, iron, and potassium.[1]

Manufacturers may also choose to add several other optional nutrients or nutritional information: calories from saturated fat, polyunsaturated fat, monounsaturated fat, soluble and insoluble fiber, sugar alcohol, other carbohydrate, and other vitamins and minerals.

4. Percent Daily Values

The ***Daily Value (DV)*** is an approximate recommendation for daily intake for a nutrient, developed by the FDA for use on food labels so that consumers can see how much of a nutrient is provided by a serving of a food relative to about how much they need each day. The DV is similar to the RDA or AI, except that because it's used on food labels, it needs to be a simplified recommendation, with just one value rather than several for different age groups and sex, as found in the DRI.[3]

Most DVs are based on amounts for people age 4 years through adult, though there are DVs established for infants, toddlers, and pregnant and lactating women, and you'll see those used on food products specifically developed for those groups. Most of the time, the DV for a nutrient is the highest RDA or AI for the group it's intended for.

The value printed on the Nutrition Facts panel is the percent DV, which tells you how much one serving of the food contributes towards meeting the daily requirement for that nutrient.

The FDA uses the following definitions for interpreting the %DV on food labels:[4]

- 5%DV or less means the food is low in a nutrient.
- 10% to 19%DV means the food is a "good source" of a nutrient.
- 20%DV or greater means the food is high in a nutrient.

The DV is not as precise as the RDA, so while the %DV is useful for comparing food products or making quick judgements about the nutritional value of a food, it's better to use the RDA if you're looking for your individual nutrient requirements.

More on the DVs

Based on a standard 2,000 kcal diet, DVs provide a general framework for evaluating how a food contributes to daily nutrient intake. Below are the Daily Values (DV) in a table, for your reference and information.

Daily Values for Nutrients on the Nutrition Facts Label (Based on 2,000 kcal diet)

Nutrient	Daily Value (DV)
Total Fat	78 g
Saturated Fat	20 g
Cholesterol	300 mg
Sodium	2,300 mg
Total Carbohydrate	275 g
Dietary Fiber	28 g
Total Sugars	*No DV established*
Added Sugars	50 g
Protein	50 g

Nutrient	Daily Value (DV)
Vitamin D	20 mcg (800 IU)
Calcium	1,300 mg
Iron	18 mg
Potassium	4,700 mg

Putting the Nutrition Facts panel to work for you

How you use the Nutrition Facts on food labels depends on your dietary goals. If you're trying to reduce your saturated fat intake, you'll want to pay close attention to the %DV for saturated fat and try to choose foods with less than 5% DV for saturated fat. If you're watching your caloric intake, you'll want to pay attention to the calorie information. Regardless, always start by checking the serving size and comparing it to the amount you usually consume.

As an example of smart label reading, take a look at the two soup labels below. First, think about how much soup you would usually consume. There are two servings per can, but would you eat the entire can or just half of it? Many people would eat the whole can, and if that's you, you would want to double all of the calorie and nutrient information. Both soups provide 160 calories per one-cup serving, or 320 calories for the entire can.

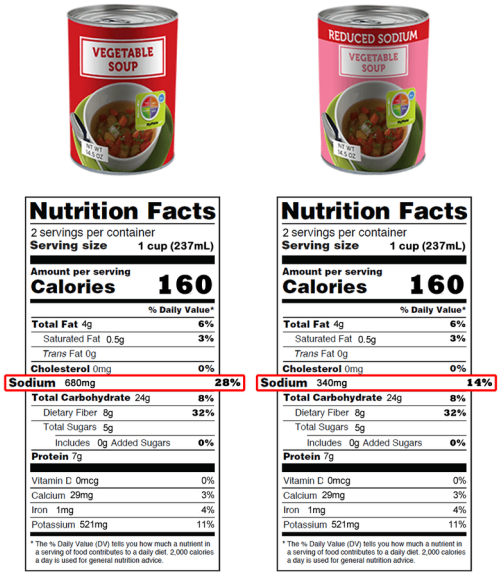


Figure 1.14. Comparison of Nutrition Facts for a regular vegetable soup, and reduced sodium vegetable soup.

Next, take a look at the sodium. Most Americans consume too much sodium, and this can increase the risk of developing high blood pressure. The regular soup has 680 mg or 28% of the DV for sodium. If you eat the entire can, that becomes 1360 mg or 56% DV. That's a lot of sodium. You can see how the reduced sodium soup might be the wiser choice here.

YouTube Video

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

View this YouTube Video online

VIDEO: "Reading Food Labels," by Cincinnati Children's, YouTube (May 9, 2019), 2:56 minutes.

What's That Claim?

In addition to the FDA-required information on food labels, it's common for them to be peppered with claims about the nutrient content of the food and the purported health benefits of eating it. These claims are marketing tools for food manufacturers, and they're regulated by the FDA in an effort to ensure that they give the consumer accurate, science-based information about the food. Let's look at the different types of claims that you'll find on food packages.

Nutrient Claims

Nutrient claims provide straight-forward information about the level of a nutrient or calories in the food, such as "fat-free," "low calorie," or "reduced sodium." Nutrient claims are regulated by the FDA, with very specific requirements for each one. For example, a food with a "low sodium" claim must have 140 mg of sodium or less per serving, whereas a food with a "reduced sodium" claim must have at least 25 percent less sodium than the standard product. You'll see claims that a food is "high in," "rich in," and "excellent source of" a nutrient, all of which mean that a serving of the food contains 20% DV or more. A "good source of" claim contains 10-19% DV of the nutrient.[1]



Figure 1.15. Examples of food packaging with nutrient claims. Can you spot them?

Health Claims

Health claims are statements on food packaging that link the food or a component in the food to reducing the risk of a disease. Health claims can be "authorized" or "qualified." ***Authorized health claims*** have stronger scientific evidence to back them than qualified health claims.[5]

As an example of an authorized health claim, a food that is low in sodium (per the FDA's definition of less than 140 mg per serving) can include the following claim on their packaging: "Diets low in sodium may reduce the risk of high blood pressure, a disease associated with many factors."[1]

For an authorized health claim to be approved by the FDA, the agency says "there must be significant scientific agreement (SSA) among qualified experts that the claim is supported by the totality of publicly available scientific evidence for a substance/disease relationship. The SSA standard is intended to be a strong standard that provides a high level of confidence in the validity of the substance/disease relationship."[5] In other words, the FDA requires a great deal of evidence before allowing food manufacturers to claim that their products can reduce the risk of a disease. As is evident in the low sodium claim, they also require careful language, such as "*may* reduce" (not definitely!) and "a disease associated with many factors" (as in, there are many other factors besides sodium that influence blood pressure, so a low sodium diet isn't a guaranteed way to prevent high blood pressure).

Qualified health claims have some evidence to support them, but not as much, so there's less certainty that these claims are

true. The FDA reviews the evidence for a qualified claim and determines how it should be worded to convey the level of scientific certainty for it. Here's an example of a qualified health claim: "Scientific evidence suggests but does not prove that eating 1.5 ounces per day of most nuts [such as name of specific nut] as part of a diet low in saturated fat and cholesterol may reduce the risk of heart disease."

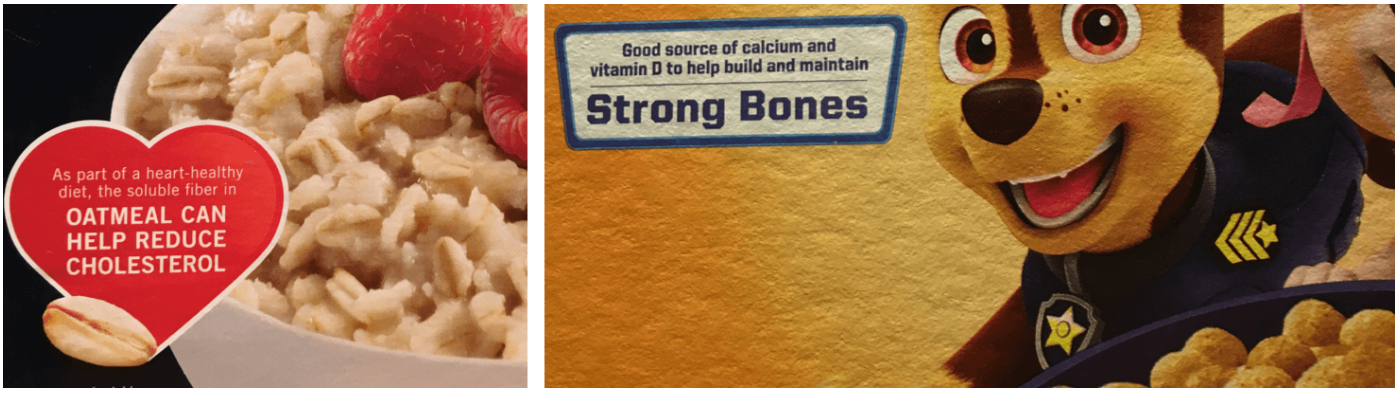


Figure 1.16. *Examples of food packaging with authorized health claims. Can you spot them?*

Structure-Function Claims

Health claims are very specific and precise in their language, and they convey the level of scientific certainty supporting them. In contrast, ***structure-function claims*** are intentionally vague statements about nutrients playing some role in health processes. Examples of structure-function claims are "calcium builds strong bones" and "fiber maintains bowel regularity." Note that these statements make no claims to prevent osteoporosis or treat constipation, because structure-function claims are not allowed to say that a food or nutrient will treat, cure, or prevent any disease.[6] They're allowed by the FDA, but not specifically approved or regulated, as long as their language stays within those rules.



Figure 1.17. *Examples of food and supplement packaging with structure-function claims. Can you spot them?*

Structure-function claims were originally designed to be used on dietary supplements, but they can also be used on foods, and they're usually found on foods that are fortified with specific nutrients. They are marketing language, and because nutrients are involved in so many processes, they really don't mean much.

As you look at food labels, pay attention to what's shown on the front of the package compared with the back and side of the package. Nutrient and health claims are usually placed strategically on the front of the package, in large, colorful displays with

other marketing messages, designed to sell you the product. But for consumers trying to decide which product to buy, you'll find the most useful information by turning the package around to read the Nutrition Facts panel and ingredients list. These parts of the label may appear more mundane, but if you understand how to read them, you'll find that they're rich in information.

References

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3.1.8: Navigating Portion Sizes

Learning Objectives

- 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 mashed potatoes on your plate, particularly if it is a big plate, and not realize that you have just helped yourself to three portions instead of one.

The food industry makes following the Dietary Guidelines for Americans a challenge. To address this, the most-recent Nutrition Facts labels now present information for serving sizes that reflect what people actually consume in practice (vs. an idealized serving size). However, in many restaurants and eating establishments, portion sizes have increased, use of saturated fat and added sugars has increased, and consequently the typical meal contains more calories than it used to. In addition, our sedentary lives make it difficult to expend enough calories during normal daily activities. In fact, more than one-third of adults are not physically active at all.

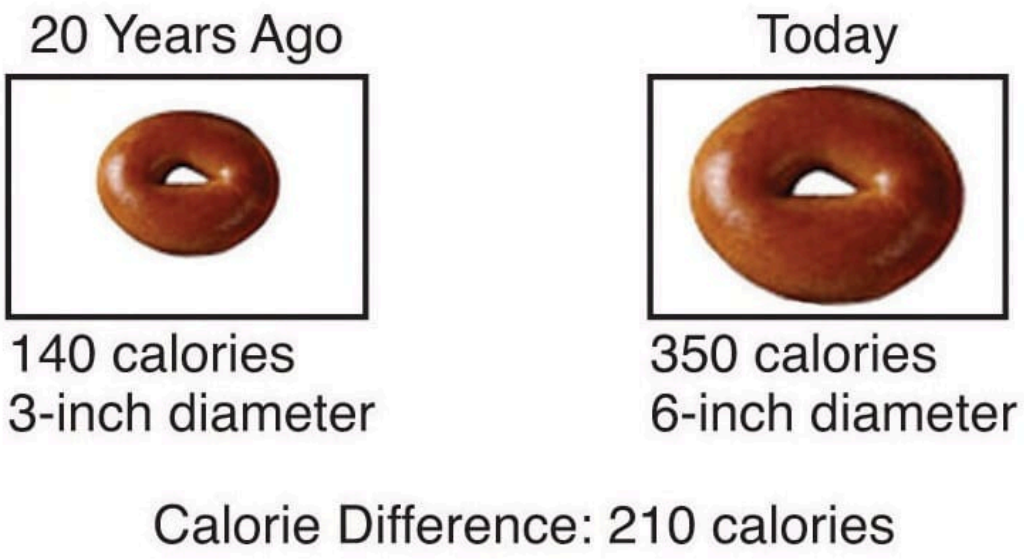


Figure 3.1.8.1: As food sizes and servings increase it is important to limit the portions of food consumed on a regular basis.

Dietitians have come up with some good hints to help people tell how large a portion of food they really have. Some suggest using common items such as a deck of cards while others advocate using your hand as a measuring rule. See Table 3.1.8.1 for some examples.American Cancer Society. “Controlling Portion Sizes.” Last revised January 12, 2012. http://www.cancer.org/Healthy/EatHealthyGetActive/TakeControlofYourWeight/controlling-portion-sizes.

Table 3.1.8.1: Determining Food Portions

Food Product	Amount	Object Comparison	Hand Comparison
Pasta, rice	½ c.	Tennis ball	Cupped hand
Fresh vegetables	1 c.	Baseball	
Cooked vegetables	½ c.	Cupped hand	

Food Product	Amount	Object Comparison	Hand Comparison
Meat, poultry, fish	3 oz.	Deck of cards	Palm of your hand
Milk or other beverages	1 c.	Fist	
Salad dressing	1 Tbsp.	Thumb	
Oil	1 tsp.	Thumb tip	

Video 3.1.8.1: How Portion Control Can Help You Maintain a Healthy Weight

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MyPlate Planner

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

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

Table 3.1.8.2: Meal Planning Guidelines

Carbohydrates	Meats/Proteins	Fats	Free Foods
Choose three servings with each meal.	Choose one to three servings with each meal.	Choose one to two servings with each meal.	Use as desired.
Examples of *one* serving:	Examples of *one* serving:	Examples of *one* serving:	Examples
Breads and Starches • 1 slice bread or small roll • ⅓ c. rice or pasta • ½ c. of cooked cereal or potatoes • ¾ c. dry cereal • ½ c. corn	• 1 oz. lean meat, poultry, or fish • 1 egg • 1 oz. cheese • ¾ c. low-fat cottage cheese	• 1 tsp. margarine, oil, or mayonnaise • 1 Tbsp. salad dressing or cream cheese	**Foods with less than 20 calories per serving.*** • Most vegetables • Sugar-free soda • Black coffee or plain tea
Fruits • 1 piece, such as a small pear • 1 c. fresh fruit • ½ c. canned fruit • ½ c. fruit juice			

Carbohydrates	Meats/Proteins	Fats	Free Foods
Milk • 1 c. skim or low fat • 1 c. unsweetened low-fat yogurt			

Key Takeaways

- Judging portion sizes can be done using your hand or household objects in comparison. It can also be done using the MyPlate guide to determine how much food is a portion for that meal.

Discussion Starter

1. Why is it important to judge portion sizes properly? Explain why it can be tricky to read food labels and figure out the caloric content for one serving.

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3.1.9: Ultra-processed Foods (UPF)

Ultra-processed foods have become a dominant feature of the modern diet, especially in high-income countries like the United States, where they account for approximately **58% of total daily calories** consumed by adults (Baraldi et al., 2018). These products — such as packaged snacks, soft drinks, frozen meals, and sweetened breakfast cereals — are designed for convenience, long shelf life, and maximum palatability, often relying on industrial ingredients and processing techniques not used in home cooking. As their prevalence has grown, so too have concerns about their potential role in rising rates of obesity, type 2 diabetes, and other chronic diseases. But what exactly makes ultra-processed foods harmful: their ingredients, their nutrient content, or the industrial processing itself?

This section explores the origins of the term "ultra-processed," the scientific evidence behind health concerns, and the growing political and regulatory interest in defining and potentially limiting these foods. Given their widespread consumption and the complexity of their health impacts, ultra-processed foods are likely to remain in the spotlight, and further research will be essential to inform clear, evidence-based guidance on their consumption.

As an introduction, the following New York Times video features Dr. Carlos Monteiro — later mentioned in this section — and introduces the concept of ultra-processed foods and illustrates how they are reshaping dietary habits in Brazil.

Interactive Content

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Video 3.1.9.1: There are now more obese than underweight adults in the world. Sales of ultraprocessed foods have more than doubled over the last decade — even spreading into low-income countries. Here's what the junk food transition looks like in Brazil. by New York Times video. September 16, 2017.

What Are Ultra-Processed Foods?

Ultra-processed foods (UPFs) are industrial formulations typically containing ingredients not used in home cooking — such as flavor enhancers, colors, emulsifiers, and other additives—designed to be hyper-palatable, shelf-stable, and convenient. Common examples include sugary cereals, packaged snacks, frozen pizzas, and soft drinks.

Origins of the Term and the NOVA Classification

The term "ultra-processed foods" was coined by Dr. Carlos Monteiro, a Brazilian nutrition researcher, who developed the NOVA classification system. This framework categorizes foods into four groups based on the extent and purpose of processing, with Group 4 being "ultra-processed".

Monteiro's team argued that processing itself, rather than just nutrient content, plays a critical role in shaping health outcomes. The NOVA system has gained traction globally, including use in public health policies in Brazil, France, and Canada.

In a compelling new episode on the podcast, *The Ty Beal Show*, Dr. Monteiro walks listeners through the origin of the term ultra-processed foods (UPFs), recounting how sharp increases in obesity in Brazil coincided not just with more sugar or fat in diets, but with a wholesale shift in consumption away from traditional meals toward industrially engineered food products. Dr. Monteiro explains why UPFs are not merely "processed" foods, but represent a new category of industrial formulations — often defined by additives, artificial ingredients, and lack of a natural "food matrix."

As you read further, you'll see how Dr. Monteiro's concept challenges nutrient-centric models of diet and health, instead calling for a systems-level appreciation of how food is made, marketed, and consumed.

Epidemiological Evidence: Health Outcomes and Consumption

Numerous large-scale observational studies have linked higher intake of ultra-processed foods to:

- Increased risk of obesity, type 2 diabetes, and cardiovascular disease
- Higher all-cause mortality rates
- Greater cancer risk, especially breast cancer

For example, a prominent 2019 study from France's NutriNet-Santé cohort found a 10% increase in ultra-processed food consumption was associated with a 14% higher risk of all-cause mortality.

However, these studies are observational, so they can't definitively prove causation.

Recent Policy and Political Attention

At the Federal Level

Ultra-processed foods have become a flashpoint in political and public health debates:

- Health Secretary Robert F. Kennedy Jr. has condemned UPFs as "poisoning" Americans, blaming them for the rise in chronic disease.
- The 2025 MAHA Commission Report stated that UPFs lead to:
  - Nutrient depletion
  - Increased caloric intake
  - Exposure to potentially harmful additives

However, the report also acknowledged the lack of rigorous trials and the ambiguity in defining UPFs, which complicates efforts to regulate them or make clear public health recommendations.

At the California State Level

In 2025, California enacted AB 1264 — the first-in-the-nation law to deliver a statutory definition of "ultra-processed foods (UPFs)" and to mandate their gradual removal from public school meals. Under the law, California public schools must phase out the most harmful UPFs beginning January 1, 2028, with full prohibition of such foods in school breakfasts and lunches by 2035. Schools will be required to rely instead on "nutritionally adequate meals" — aligning with existing meal-service mandates but shifting the composition toward minimally processed or whole-food options.

Hypothetically and in actual practice, AB 1264 could have substantial beneficial nutritional impacts for school-age children. By removing UPFs — often high in added sugars, saturated fat, sodium, and industrial additives — the law might reduce children's exposure to dietary patterns linked by growing research to obesity, type-2 diabetes, cardiovascular disease, metabolic disorders, and other long-term health risks. For many children, especially those coming from food-insecure households, school meals constitute a large portion of their daily caloric intake; thus, shifting school-provided food toward whole grains, fruits, vegetables, and less-processed proteins could improve nutritional quality, support healthy growth and development, and promote better long-term health trajectories.

In practical terms, AB 1264 could also influence broader structural aspects of school nutrition services. The requirement to substitute UPFs may prompt school districts to re-evaluate their sourcing and meal-planning practices — potentially building capacity for scratch-cooked or minimally processed meals, increasing use of local produce, and integrating healthier menu planning. Implementation might entail logistical challenges, including revising procurement contracts, retraining kitchen staff, adjusting budgets, and ensuring acceptability and uptake among students. Over time, however, the law could reshape school food environments and reduce dependence on ultra-processed convenience items, thereby helping to cultivate healthier eating habits during a critical developmental period for school-age children.

Scientific Debate and Definition Challenges

There is no universally accepted definition of ultra-processed foods, which has made consensus difficult. Critics of the NOVA

system argue that it is too broad and may lump nutrient-dense processed foods (like whole grain breads and plain, unsweetened yogurt) with UPF products that are clearly deleterious edible substances.

Meanwhile, the Trump administration has initiated efforts to develop a "government-wide definition" for UPFs, though no formal framework has yet been finalized.

Processing vs. Ingredients: What Matters Most?

There are two concerns: the ingredients, and the actual processing.

Although the current Dietary Guidelines for Americans focus on limiting added sugar, sodium, and saturated fat, processing techniques themselves (like emulsification, extrusion, or flavor enhancement) are largely unstudied in policy contexts.

This gap in understanding underscores the need for more mechanistic and behavioral research into how processing affects satiety, metabolism, and long-term health.

Clinical Trials: What the Kevin Hall NIH Study Tells Us

Using the most rigorous experimental design — a randomized controlled trial in humans — Dr. Kevin Hall at the U.S. NIH directed landmark study in 2019 that provided compelling evidence that ***processing itself may be a key driver of weight gain*.**

Human participants were given two diets matched for calories, macronutrients, sugar, sodium, and fiber — one made up of ultra-processed foods, the other of minimally processed foods. The result:

- Participants on the ultra-processed diet consumed ~500 more calories/day
- They gained ~2 pounds in two weeks, while those on the unprocessed diet lost weight

This was the first tightly controlled trial in humans to suggest that even when nutrient content is held constant, ultra-processing alters eating behavior and metabolism, possibly by affecting satiety cues or eating speed.

New Lancet Series on Ultra-Processed Foods and Human Health

A recent three-part **Lancet Series on Ultra-Processed Foods and Human Health** offers a landmark synthesis of evidence linking ultra-processed foods (UPFs) — highly industrialized, additive-laden, shelf-stable products — with widespread deterioration of diet quality and a rising burden of chronic disease. The first paper reviews decades of national diet surveys, purchase data, and global sales trends to show that UPFs are rapidly displacing traditional diets based on fresh or minimally processed foods. It finds that diets dominated by UPFs tend to feature excessive energy density, poor nutrient balance (too much sugar, fat, and salt; too little fiber and phytochemicals), exposure to potentially harmful additives and contaminants, and overstimulation of appetite through “hyper-palatability.” The third paper documents consistent associations across more than 100 prospective studies, randomized trials, and mechanistic research linking high UPF consumption to elevated risk of obesity, type-2 diabetes, cardiovascular disease, depression, and premature mortality across multiple organ systems.

Importantly, the authors argue these findings constitute enough evidence to justify immediate Public Health action — not just individual behavior change — because waiting for perfect long-term trials risks embedding UPFs even more deeply into global food systems. They lay out a comprehensive policy agenda: front-of-pack labels marking UPF-characteristic additives, strict restrictions on marketing (especially child-directed and digital advertising), removal of UPFs from cafeterias in schools, hospitals, and other public institutions, strategic taxes on ultra-processed items, and subsidies or support for fresh and minimally processed foods — particularly in low-income communities.

At the same time, the series calls for more research to clarify mechanisms, long-term outcomes, and potential heterogeneity within the UPF category (because ultra-processed foods differ widely). Meanwhile, researchers emphasize that the political and economic power of global food corporations — using aggressive marketing, lobbying, and influence over policy — is a major barrier to effective reform.

To explore the full arguments, data, and policy recommendations, the series is freely accessible online via The Lancet. The first article is titled “*Ultra-processed foods and human health: the main thesis and the evidence*”

The Path Forward: Toward Clearer Guidelines

Despite growing evidence and public concern, the field still faces several challenges:

- Defining UPFs precisely and consistently
- Conducting more rigorous, long-term trials
- Balancing public health messaging to avoid stigmatizing nutrient-dense processed foods, such as fortified foods

A more nuanced framework could emerge — one that distinguishes between "harmfully ultra-processed" foods and those that are technologically processed yet health-promoting. Given their growing presence in global diets and the ongoing debate over their health impacts, ultra-processed foods are likely to remain in the spotlight, and further research will be essential to inform clear, evidence-based guidance on their consumption.

As part of its mandate to promote healthier, safer, and more sustainable diets, the **World Health Organization (WHO)** has convened a **Guideline Development Group (GDG) for Ultra-processed Foods** composed of experts from diverse disciplines — nutrition science, food technology, epidemiology, public health, policy, and related fields — selected through an open call and global outreach. This provisional group will undergo review by the WHO Guidelines Review Committee, and member biographies are being shared publicly for transparency and comment.

This group will play a central role in both shaping and advancing this research landscape while developing the first global guideline on UPF consumption. As part of the guideline development process, experts will:

- **Define the Guideline Scope:** Provide input on the conceptual and practical boundaries of the guideline, ensuring that it addresses the most pressing scientific and public health questions related to UPFs.
- **Develop Key Questions for Evidence Review:** Help craft the analytic questions that will structure systematic reviews, including inquiries related to health outcomes, populations of interest, and relevant dimensions of food processing.
- **Prioritize Outcomes and Inform Recommendations:** Identify which health, behavioral, and policy outcomes are most critical for decision-making and use these priorities to guide the assessment of evidence and recommendation development.
- **Evaluate the Evidence Base:** Examine and interpret the available data with explicit attention to the balance of risks and benefits associated with UPF consumption, considering both nutrient-related and processing-related pathways.
- **Formulate Evidence-Informed Recommendations:** Integrate scientific findings with considerations of values and preferences, feasibility, equity, cultural acceptability, socioeconomic contexts, and resource implications.
- **Identify Research Gaps:** Highlight areas where evidence is insufficient or inconsistent and underscore priority topics for future investigation, helping to orient the global research agenda.
- **Review the Final Guideline:** Ensure that the final document reflects rigorous evidence appraisal, methodological transparency, and consensus among diverse experts.

Through these activities, the GDG will directly support the scientific and methodological advancement of UPF research. Their work will complement broader research priorities — including elucidating causal mechanisms, refining UPF classification and measurement, understanding socioeconomic and global food system drivers, evaluating interventions, and examining life-course exposures. Together, these efforts will strengthen the evidence foundation needed for clear, actionable global dietary guidance and inform future investigations aimed at reducing diet-related disease and improving population health.

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3.2: Assessing Alignment with the DGA, Physical Activity Goals, and Healthy People 2030 Goals

This section explores how well Americans are meeting key national health benchmarks, including adherence to the Dietary Guidelines for Americans (DGA), achievement of physical activity recommendations, and progress toward the broader objectives outlined in Healthy People 2030. It examines current data on diet quality, nutrient intake, and activity levels across different age groups and populations, highlighting areas of success as well as ongoing challenges. The section also discusses factors influencing these outcomes, such as social determinants of health, lifestyle behaviors, and public health initiatives. By understanding where gaps remain, readers will gain insight into priorities for future nutrition and physical activity interventions designed to improve overall health and reduce chronic disease risk.

Learning Objectives:
By the end of this section, students will be able to:

1. Describe the current status of Americans' dietary patterns relative to the Dietary Guidelines for Americans.
2. Explain how well various populations meet recommended physical activity guidelines and identify key barriers.
3. Summarize the goals of Healthy People 2030 related to nutrition and physical activity.
4. Analyze factors contributing to disparities in diet quality and physical activity levels.
5. Evaluate the implications of current data for public health strategies aimed at improving nutrition and physical activity nationwide.

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3.2.1: NHANES — National Health and Nutrition Examination Survey

Overview

The National Health and Nutrition Examination Survey (NHANES) is a key source of data for assessing the diet and health of the U.S. population. NHANES collects detailed information through interviews, 24-hour dietary recalls, physical examinations, and laboratory tests from a nationally representative sample. These data allow researchers to evaluate nutrient intakes, diet quality, and adherence to the Dietary Guidelines for Americans. Measures like the Healthy Eating Index (HEI) rely on NHANES data to track trends in dietary patterns and monitor progress toward national nutrition objectives, such as those outlined in Healthy People 2030.

NHANES: Methods, Strengths, and Applications in Nutrition Science

Methods

The National Health and Nutrition Examination Survey (NHANES) is the pre-eminent source of comprehensive, nationally representative data on the nutritional and health status of the civilian, non-institutionalized population of the United States. Its roots go back to the early 1960s, under the authority of the National Health Survey Act of 1956, when the first national health-examination surveys (called NHES I–III) were conducted. In 1971, the survey expanded to include a detailed nutrition component — from that point on it became known as NHANES. Beginning in 1999, NHANES shifted to a continuous, rolling-survey model, collecting data every year, with public releases usually aggregated into two-year "cycles" (e.g., 1999–2000, 2001–2002, etc.). The most recent cycle, accounting for post-COVID adjustments, covers August 2021 through August 2023.

A key strength of NHANES is its sampling design, which intentionally oversamples certain subpopulations at greater risk of nutrition- or health-related conditions — for example, low-income individuals, older adults, and racial/ethnic minorities (Hispanic, non-Hispanic Black, non-Hispanic Asian) depending on the cycle. This oversampling ensures that these groups are represented with sufficient numbers to produce reliable estimates for their health and nutritional status — a critical advantage when monitoring health disparities and informing tailored nutrition policies.

Applications

NHANES has had enormous impact on health and nutrition policy in the U.S. Because it combines self-reported information (diet, lifestyle, demographics) with objective physical measurements (height, weight, blood pressure), clinical measurements (e.g. blood lipids, micronutrient levels), and even toxicology / environmental exposure data, it allows for robust population-wide estimates of both diet quality and disease risk. For example, data from NHANES have informed national standards (e.g., growth charts, definitions of overweight/obesity, blood pressure and cholesterol thresholds), helped identify national prevalence of undernutrition, micronutrient deficiencies, obesity, hypertension, diabetes, and others — which in turn influence dietary recommendations, fortification policies, screening guidelines, and public-health interventions. Because NHANES is repeated regularly and nationally representative, it allows for tracking trends in diet quality, nutrient intake, disease prevalence, and risk factors — contributing to ongoing evaluation of how well the population adheres to the Dietary Guidelines for Americans (DGA), the calculations of indexes such as the Healthy Eating Index (HEI), and the monitoring of progress towards national health-objectives such as those in Healthy People 2030.

Strengths

Compared with large-scale telephone-based surveys such as Behavioral Risk Factor Surveillance System (BRFSS), NHANES offers critical advantages. Telephone-based surveys rely solely on self-reported data — people's recall of diet, lifestyle, and health conditions — which are subject to recall bias, misreporting, and limited ability to capture undiagnosed disease or biochemical risk factors (e.g., subclinical deficiencies, elevated cholesterol, hypertension). By contrast, NHANES' in-person interviews, mobile examination center (MEC) visits, and lab-based measurements allow for accurate, standardized assessment of body measurements, blood and urine biomarkers, nutrient status, environmental exposures, and objectively-measured health outcomes. This makes NHANES uniquely powerful for linking dietary intake, environmental exposures, and lifestyle factors to objectively measured health and disease risk — a feature that is essential for evidence-based nutrition policy and public health research.

Challenges and the Future of NHANES

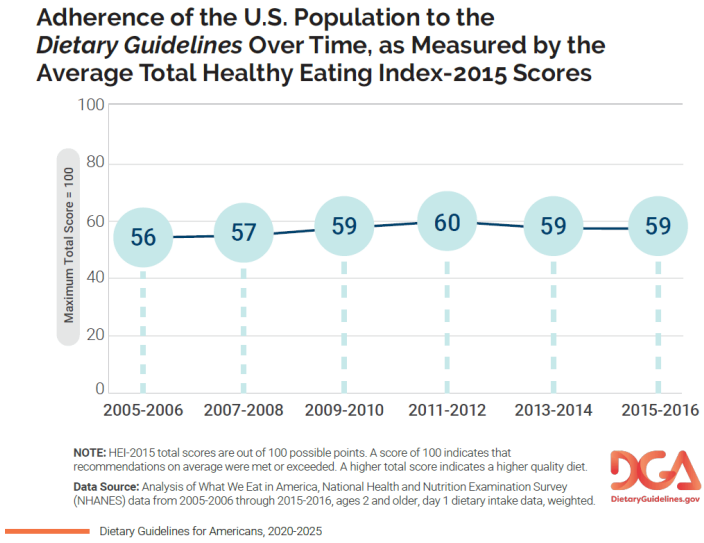
NHANES is not immune to political and resource pressures. As of October 2025, the survey's future has come under serious threat: staff responsible for planning and coordinating NHANES at the National Center for Health Statistics (NCHS) within the Centers for Disease Control and Prevention (CDC) were among those laid off during a sweeping reorganization of the U.S. Department of Health and Human Services (HHS) under the current administration. Although public pressure led to reinstatement of some employees, the future of the core NHANES planning team is uncertain. This has raised serious concerns among health researchers and policy analysts about whether NHANES can continue its vital role in generating nationally representative health and nutrition data — particularly at a time when such data may be needed more than ever.

Looking ahead, the prospects for NHANES depend on political will, stable funding, and institutional commitment to maintaining a high-quality, comprehensive surveillance system. If support continues, NHANES is positioned to remain the cornerstone for evaluating dietary patterns, monitoring nutrient intake and deficiencies, assessing environmental exposures, and informing updates to dietary guidelines and public health policy. But if funding or staffing erodes, the United States risks losing an objective, scientifically rigorous foundation for nutrition surveillance. Emphasizing NHANES' role — and the fragility of such public-health infrastructure — highlights that nutrition policy depends not only on science, but also on sustained public and political support.

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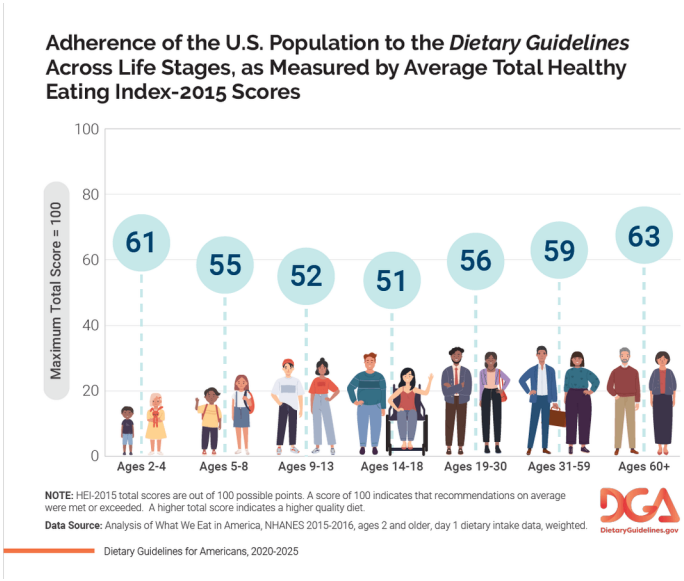
The Healthy Eating Index (HEI) is a measure developed by the U.S. Department of Agriculture to assess how well a person's diet aligns with the Dietary Guidelines for Americans (DGA). It evaluates overall diet quality by scoring intake across key food groups and nutrients that the DGA prioritizes, such as fruits, vegetables, and whole grains, as well as things to limit, such as sodium, saturated fat and added sugars, on a scale of 0 to 100. A higher HEI score reflects a diet more aligned to the DGA. This tool is important because it provides a standardized way to examine diet quality at the individual, group, and population levels, helping identify nutritional gaps and areas for improvement.

For example, the figure below shows how the U.S. population's eating habits have compared to the Dietary Guidelines for Americans (DGA) from 2005 to 2016. During this time, overall diet quality stayed consistently below recommended levels. This highlights a continued need to improve how we eat and make choices that better align to the DGA to support long-term health.



For adolescents and college-age students — who often experience changes in eating patterns due to increased independence and busy schedules — the HEI can be especially useful. Schools, health professionals, and researchers use the HEI to design interventions, track dietary habits, and promote healthier food choices, ultimately supporting long-term health and reducing the risk of chronic diseases.

The figure below presents the most-recent HEI scores for different age groups, showing that individuals aged 14–18 years have the lowest average score.



Interpreting HEI scores

- These scores indicate that, across all age groups, diets in the U.S. fall short of perfect alignment with the Dietary Guidelines (i.e. a score of 100).
- Younger children and older adults tend to score somewhat higher, on average, than adolescents and middle-aged adults.
- Because these are mean values based on 24-hour recall data from surveys (e.g. NHANES / What We Eat in America), they represent average population-level diet quality, not individual diets.

A deeper look into what is driving the low score for Dietary Patterns of U.S. Adolescents (Ages 14–18) is shown in the images below, which are taken from this source.

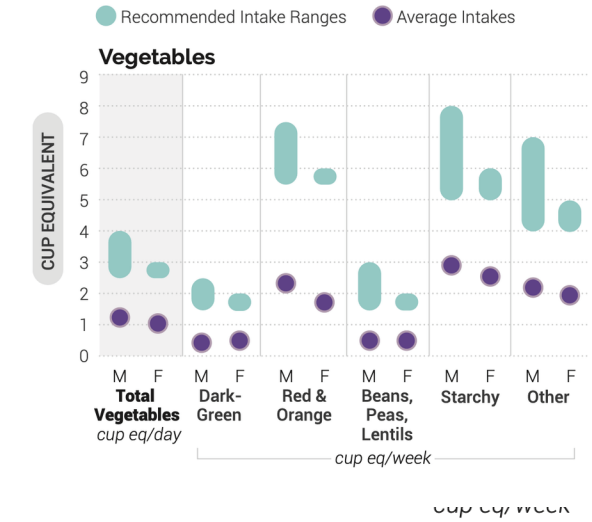
Between 2015 and 2016, researchers assessed how closely the diets of U.S. adolescents aged 14 to 18 aligned with the federal Dietary Guidelines for Americans. Using the Healthy Eating Index (HEI), which scores diet quality on a scale from 0 to 100, they found that this age group had an average score of 51 out of 100. This means that, on average, teens are meeting only about half of the recommended dietary goals.

The report highlighted several areas of concern. A large number of adolescents consume more added sugars, saturated fats, and sodium than the guidelines recommend. For example, most teens exceed the daily limit for sodium — set at 2,300 milligrams — as well as the recommendation that no more than 10% of daily calories come from added sugars and saturated fat.

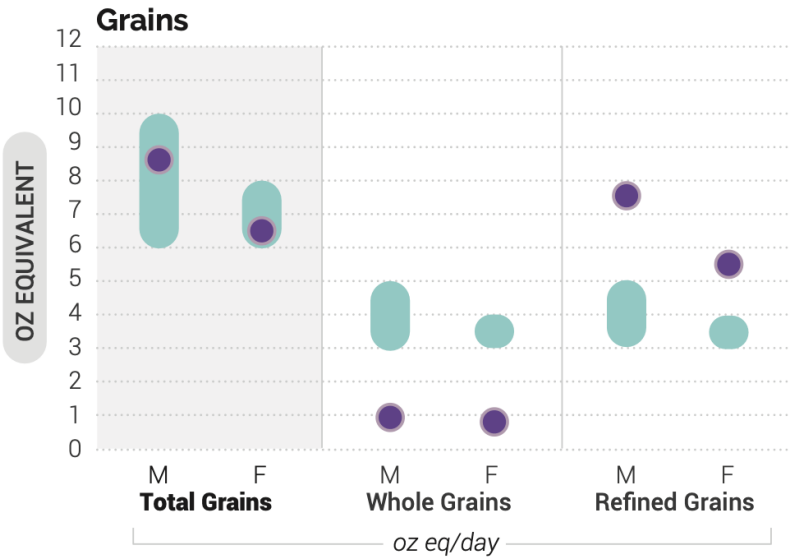
The report also includes detailed breakdowns for specific food groups like different types of vegetables, protein foods, and grains. The overall low HEI score is driven not only by overconsumption of things to limit, but also by inadequate intakes of all vegetable types, whole grains, seafood, nuts, seeds, and soy products. In sum, many teens are eating not enough nutrient-rich foods and too many foods high in salt, sugar, and saturated fat than is ideal.

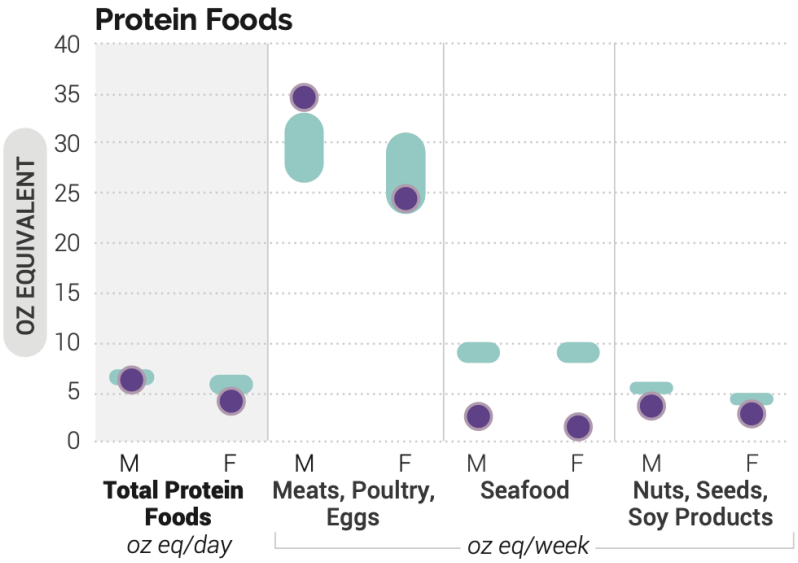
These findings point to opportunities to support teens in making healthier food choices — such as increasing intake of vegetables, fruits, whole grains, and a variety of protein foods, especially beans, nuts and seeds, while reducing sugary snacks, salty ultra-processed foods, and sugary drinks.

Average Intakes of Subgroups Compared to Recommended Intake Ranges: Ages 14 Through 18



Data Sources: *Average Intakes*: Analysis of What We Eat in America, NHANES NHANES 2015-2016, day 1 dietary intake data, weighted. *Recommended Intake Ranges:* Healthy U.S.-Style Dietary Patterns (see ***Appendix 3***).





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3.2.3: National Goals for Nutrition and Health — Healthy People 2030

Learning Objectives

- State the Healthy People 2030 nutrition- and weight-status goals.
- List three related objectives for the Healthy People 2030 program.

Healthy People 2030

Healthy People 2030 is the current national framework for improving the health and well-being of people in the United States over the decade. Led by the U.S. Department of Health and Human Services (HHS), this initiative sets measurable objectives across key health topics, including nutrition, physical activity, chronic disease, mental health, and health equity. One of its core goals is to eliminate health disparities and create environments that support healthy choices for all individuals. In the area of nutrition, Healthy People 2030 emphasizes increasing consumption of nutrient-dense foods (like fruits, vegetables, and whole grains), reducing added sugars and sodium, and addressing food insecurity. Compared to previous versions — Healthy People 2020 — this version places a stronger emphasis on social determinants of health, cross-sector collaboration, and the use of data to guide action. It provides tools, evidence-based resources, and progress tracking to support policymakers, educators, public health professionals, and communities in reaching national health goals.

Much of the information presented in this chapter is based on Healthy People 2020, which provided the foundation for many of today's national nutrition goals and strategies. While Healthy People 2020 focused on identifying measurable objectives to improve health behaviors and outcomes, it also revealed gaps and challenges that informed the development of Healthy People 2030. The newer framework builds on its predecessor but introduces several important shifts in approach and emphasis that reflect current public health priorities. Notably, Healthy People 2030:

- Reduces the number of objectives to focus more clearly on the most critical health priorities.
- Places a stronger emphasis on health equity and addressing social determinants of health.
- Includes a new overarching goal to engage leadership, key constituents, and the public across multiple sectors to take action and design policies that improve health.
- Provides enhanced tools and data-tracking capabilities to support evidence-based decision-making.
- Aligns more closely with initiatives like the Dietary Guidelines for Americans and CDC's public health frameworks.

Together, these updates in Healthy People 2030 reflect a more integrated and equity-driven approach to nutrition and public health in the decade ahead.

Healthy People 2030 Official resources:

- Healthy People 2030 main website: https://health.gov/healthypeople
- Nutrition and Healthy Eating objectives: https://health.gov/healthypeople/obj...healthy-eating
- Healthy People 2030 Framework: https://odphp.health.gov/healthypeop...2030-framework

Healthy People 2020

Healthy People 2020 played a pivotal role in guiding national health promotion and disease prevention efforts over the past decade, including a strong focus on nutrition and dietary behaviors. Key findings from the initiative showed some progress, such as increased vegetable intake among young children and modest improvements in whole grain consumption. However, many nutrition-related targets — like reducing obesity rates and limiting added sugar intake — were not fully met, highlighting persistent disparities and systemic challenges in food access and diet quality. These outcomes helped shape the priorities for Healthy People 2030 by reinforcing the need for a more holistic, equity-focused approach to nutrition policy. As a result, present-day efforts emphasize community-based interventions, food environment improvements, culturally relevant nutrition education, and stronger alignment with the Dietary Guidelines for Americans. The lessons learned from Healthy People 2020 continue to inform

strategies aimed at reducing chronic disease risk and promoting health across all population groups.

The Healthy People 2020 program, launched in 2010, was a ten-year national program instituted by the US government with objectives aimed toward improving the health of all Americans. Similar to the *2010 Dietary Guidelines*, it was established to promote longer lives free of preventable disease, disability, injury, and premature death. With a revived intent on identifying, measuring, tracking, and reducing health disparities through a "determinants of health approach," Healthy People 2020 strived to create the social and physical environments that promote good health for all and to promote quality of life, healthy development, and healthy behaviors across all life stages. This means that the understanding of what makes and keeps people healthy is consistently refined. The determinants of health approach reflects the evidence from outside factors that greatly affect the health of individuals.(x) It takes into consideration the circumstances in which people are born, live, work, and age. It also reflects the conditions that shape their circumstances such as money, power, and resources at the local, national, and global levels. Social determinants of health are primarily accountable for the lack of fair health opportunities and the unjust differences in health status that exist within and between countries.World Health Organization. "Social Determinants of Health." © 2012. http://www.who.int/social_determinants/en/.

Video 3.2.3.1: Preparing for the Next Decade

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"Preparing for the Next Decade: A 2020 Vision for Healthy People" by Office of Disease Prevention and Health Promotion is in the Public Domain

Helping People Make Healthy Choices

It is not just ourselves, the food industry, and federal government that shape our choices of food and physical activity, but also our sex, genetics, disabilities, income, religion, culture, education, lifestyle, age, and environment. All of these factors must be addressed by organizations and individuals that seek to make changes in dietary habits. The socioeconomic model incorporates all of these factors and is used by health-promoting organizations, such as the USDA and the HHS to determine multiple avenues through which to promote healthy eating patterns, to increase levels of physical activity, and to reduce the risk of chronic disease for all Americans.



Figure 3.2.3.1: The socioeconomic model helps organizations and the government to plan and promote effective healthy-eating programs tailored to specific populations. © Networkgraphics

Lower economic prosperity influences diet specifically by lowering food quality, decreasing food choices, and decreasing access to enough food. As a result of the recent financial crisis in America the number of people who struggle to have enough to eat is rising and approaching fifty million. In response to these recent numbers, former USDA Secretary Tom Vilsack said, "These numbers are a wake-up call...for us to get very serious about food security and hunger, about nutrition and food safety in this country."Amy Goldstein, "Hunger a Growing Problem in America, USDA Reports," *Washington Post*, 17 November 2009. www.washingtonpost.com/wp-dyn...111601598.html.

Healthy People 2020 Goals for Nutrition and Weight Status

Although Healthy People 2020 had many goals and objectives, the focus here will be on the two goals for nutrition and weight status. They are to promote health and reduce the risk of developing chronic diseases by encouraging Americans to consume healthful diets and to achieve and maintain healthy body weights. Nutrition criteria are reflective of a solid scientific foundation for health and weight management. Emphasis is on modifying individual behavior patterns and habits, and having policies and environments that will support these behaviors in various settings, such as schools and local community-based organizations.



Figure 3.2.3.2: One of the ways that Healthy People 2020 strives to promote good health and nutrition is by bringing together multiple agencies and groups dedicated to achieving the Healthy People 2020 nationwide objectives. © Shutterstock

Healthy People 2020 defined their mission as:

- Identify nationwide health improvement priorities
- Increase public awareness and understanding of the determinants of health, disease, and disability, and the opportunities for progress
- Provide measurable objectives and goals that are applicable at the national, state, and local levels
- Engage multiple sectors to take actions to strengthen policies and improve practices that are driven by the best knowledge
- Identify critical research, evaluation, and data-collection needs

Healthy People 2020 had set key recommendations as follows:

- Consume a variety of nutrient-dense foods within and across the food groups, especially whole grains, fruits, vegetables, low-fat or fat-free milk or milk products, and lean meats and other protein sources
- Limit the intake of saturated fat and trans fats, cholesterol, added sugars, sodium (salt), and alcohol
- Limit caloric intake to meet caloric needsUS Department of Health and Human Services. "Nutrition and Weight Status." HealthyPeople.gov. Last updated May 1, 2012. http://healthypeople.gov/2020/topicsobjectives2020/overview.aspx?topicid=29



Figure 3.2.3.3: Consuming nutrient-dense foods and limiting portion sizes of food will contribute to weight management. Avoiding excessive amounts of anything allows room for many food types in the diet. © Dreamstime

Tools for Change

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

Benefits of Following the Healthy People 2020 Goals

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

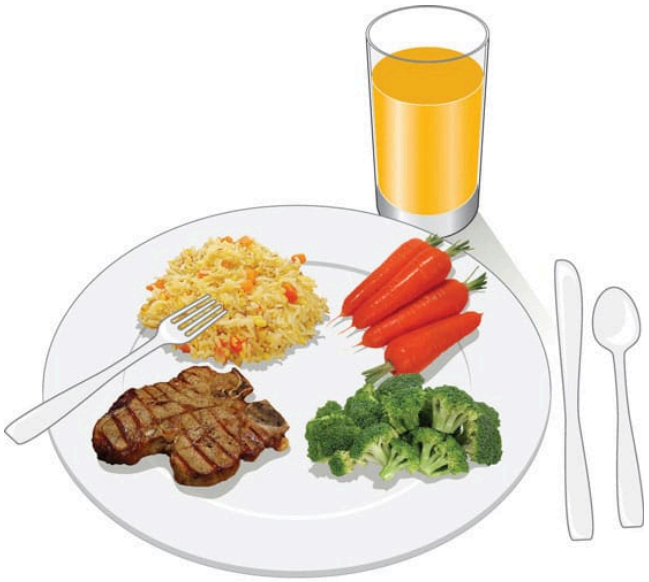


Figure 3.2.3.4: Following the *2015 Dietary Guidelines* will promote nutrition, weight loss, and weight maintenance as well as the reduction of chronic disease. © Networkgraphics

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

Objectives Related to the Healthy People 2020 Goals

Seven out of every ten deaths in the United States are caused by chronic diseases, such as heart disease, cancer, and diabetes, and three-quarters of the country's health spending goes toward the cost of treating these diseases. Helping people lose weight, maintain a healthy weight, and prevent chronic disease by improving dietary habits requires providing education about food and nutrition, assuring access to healthier food options, and promoting the desire and ability to become physically active. Some of the Healthy People 2020 program's related objectives are discussed below.

1. **Improve health, fitness, and quality of life through daily physical activity.** The Healthy People 2020 objectives for physical activity are based on the *2008 Physical Activity Guidelines for Americans*, and reflect the strong scientific evidence supporting the benefits of physical activity. More than 80 percent of the current US population, from youth to adults, is not meeting these guidelines. Healthy People 2020 highlights the way that one's level of physical activity is affected by environmental factors such as the availability of safe sidewalks, bike lanes, trails, and parks. It also highlights the legislative policies that improve access to facilities that promote physical activity. Understanding that personal, social, economic, and environmental barriers to physical activity all have a part in determining a population's physical activity level, is an important part of being able to provide interventions that foster physical activity. Consistent physical activity is necessary for preventing chronic disease, improving bone health, decreasing body fat, and preventing an early death.
2. **Increase the quality, availability, and effectiveness of educational and community-based programs designed to prevent disease and injury, improve health, and enhance quality of life.** Healthy eating is a learned behavior. By increasing the number of community-based programs (schools, workplace, health-care facilities, local community groups) that offer guidance for healthy eating and lifestyle choices, people of all ages will learn good eating habits and will gain access to good food choices to help improve their diet and overall health.
3. **Improve the development, health, safety, and well-being of adolescents and young adults.** Adolescents (ten to nineteen years of age) and young adults (twenty to twenty-four years of age) constitute 21 percent of the population of the United States. The financial burdens of preventable health problems and associated long-term costs of chronic diseases in this demographic group have the potential to be vast, and will be the result of attitudes and behaviors initiated during adolescence. For example, the annual adult health-related financial burden of cigarette smoking, which usually starts by age eighteen, is $193 billion.Adhikari, B. et al. "Smoking-Attributable Mortality, Years of Potential Life Lost, and Productivity Losses—United States, 2000–2004." *MMWR CDC Surveill Summ* 57, no. 45 (November 14, 2008): 1226–8. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5745a3.htm.



Figure 3.2.3.5: Healthy children will lead to a healthy adult population with less disease, lower healthcare costs, and increased longevity. © Shutterstock

4. **Reduce the consumption of calories from solid fats and added sugars (SoFAS) in the population aged two years and older.** A diet high in SoFAS contributes to excessive weight gain and poor health. Added sugars provide no nutritional value to foods. Excessive fat and sugar intake promotes tooth decay, obesity, Type 2 diabetes, unhealthy cholesterol levels, and heart disease. Being overweight increases susceptibility for developing high blood pressure, diabetes, cardiovascular diseases, and certain types of cancer. The evidence is clear that many chronic diseases are linked to unhealthy dietary patterns. Excessive consumption of SoFAS, in combination with the lack of plant-based foods, may contribute to higher rates of developing chronic diseases.

For more information on Healthy People 2020 and its related objectives for nutrition and weight status, please visit the website http://www.healthypeople.gov/2020.

Key Takeaways

- Healthy People 2020 was a health initiative with a ten-year objective of helping Americans improve health and well-being, and to live long, healthy lives. Among its many objectives are to promote health and reduce the risk of developing chronic diseases by encouraging Americans to consume healthful diets and to achieve and maintain healthy body weights.
- The goals of Healthy People 2020 were founded upon a determinants of health approach, which means they were reflective of the circumstances in which people are born, live, and work, as well as the conditions that shape their circumstances such as money, power, and resources at the local, national, and global levels. Diet patterns are influenced by genetics, environment, and cultural values. All of these things must be considered to provide the optimal approach to improving the health of the American population.
- Decreasing caloric intake and increasing physical activity were important strategies in achieving the goals of the Healthy People 2020 program.

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3.2.4: Physical Activity and Lifestyle

Learning Objectives

- Distinguish the major differences in physical activity guidelines between different age groups.



Figure 3.2.4.1: Photo by Luis Quintero on Unsplash / Unsplash License

Physical Activity

In 2018, the United States Department of Health and Human Services' Office of Disease Prevention and Health Promotion (ODPHP) released the second edition of the Physical Activity Guidelines for Americans[1]. The ODPHP states that "the Physical Activity Guidelines is an essential resource for health professionals and policy makers. It includes recommendations for Americans ages 3 years and over — including people at increased risk of chronic disease — and provides evidence-based advice on how physical activity can help promote health and reduce the risk of chronic disease. The Guidelines serves as the primary, authoritative voice of the federal government for evidence-based guidance on physical activity, fitness, and health for Americans."

According to the Physical Activity Guidelines for Americans, "being physically active is one of the most important actions that people of all ages can take to improve their health." "Physical activity fosters normal growth and development and can make people feel better, function better, sleep better, and reduce the risk of a large number of chronic diseases. Health benefits start immediately after exercising, and even short episodes of physical activity are beneficial. Even better, research shows that just about everyone gains benefits: men and women of all races and ethnicities, young children to older adults, women who are pregnant or postpartum (first year after delivery), people living with a chronic condition or a disability, and people who want to reduce their risk of chronic disease. The evidence about the health benefits of regular physical activity is well established, and research continues to provide insight into what works to get people moving, both at the individual and community level. Achieving the benefits of physical activity depends on our personal efforts to increase activity in ourselves, family, friends, patients, and colleagues. Action is also required at the school, workplace, and community levels."[2] The following key guidelines are included in the Physical Activity Guidelines for Americans.

As of 2025, adherence to the Physical Activity Guidelines for Americans remains a significant public health concern. According to the CDC, only about 1 in 4 U.S. adults meet the combined recommendations for aerobic and muscle-strengthening activities. While there has been a slight improvement in inactivity rates — from 27.0% in 2020 to 26.2% in 2024 — these changes are not statistically significant CDC. Physical inactivity contributes to approximately 1 in 10 premature deaths and incurs $117 billion in annual healthcare costs CDC. Notably, only 39% of Americans live within half a mile of a park, highlighting the importance of

accessible environments in promoting physical activity CDC.

The CDC's "Active People, Healthy Nation" initiative aims to help 27 million Americans become more physically active by 2027, emphasizing the need for community-based strategies to increase physical activity across various settings CDC. While progress is being made, continued efforts are essential to address the barriers to physical activity and improve public health outcomes.

Key Guidelines for Preschool-Aged Children

- Preschool-aged children (ages 3 through 5 years) should be physically active throughout the day to enhance growth and development.
- Adult caregivers of preschool-aged children should encourage active play that includes a variety of activity types.

Key Guidelines for Children and Adolescents

- It is important to provide young people opportunities and encouragement to participate in physical activities that are appropriate for their age, that are enjoyable, and that offer variety.
- Children and adolescents ages 6 through 17 years should do 60 minutes (1 hour) or more of moderate-to-vigorous physical activity daily:
  - Aerobic: Most of the 60 minutes or more per day should be either moderate- or vigorous intensity aerobic physical activity and should include vigorous-intensity physical activity on at least 3 days a week.
  - Muscle-strengthening: As part of their 60 minutes or more of daily physical activity, children and adolescents should include muscle-strengthening physical activity on at least 3 days a week.
  - Bone-strengthening: As part of their 60 minutes or more of daily physical activity, children and adolescents should include bone-strengthening physical activity on at least 3 days a week.

Recent data show that many American children are still falling short of meeting these Physical Activity Guidelines. According to the CDC, only about 24% of children ages 6 to 17 achieve this guideline consistently. Sedentary behaviors, such as screen time, remain a major barrier, with many children spending multiple hours a day on electronic devices. Moreover, disparities exist by age, gender, and socioeconomic status, with girls and older adolescents typically being less active than boys and younger children. Efforts like the CDC's "Active People, Healthy Nation" initiative are focusing on schools and communities to create supportive environments that encourage physical activity among youth. Despite some progress, increasing physical activity in children remains critical to combat rising rates of childhood obesity and related health issues.

Key Guidelines for Adults

- Adults should move more and sit less throughout the day. Some physical activity is better than none. Adults who sit less and do any amount of moderate-to-vigorous physical activity gain some health benefits.
- For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) 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, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Preferably, aerobic activity should be spread throughout the week.
- Additional health benefits are gained by engaging in physical activity beyond the equivalent of 300 minutes (5 hours) of moderate-intensity physical activity a week.
- Adults should also do muscle-strengthening activities of moderate or greater intensity and that involve all major muscle groups on 2 or more days a week, as these activities provide additional health benefits.

Key Guidelines for Older Adults

The key guidelines for adults also apply to older adults. In addition, the following key guidelines are just for older adults:

- As part of their weekly physical activity, older adults should do multicomponent physical activity that includes balance training as well as aerobic and muscle-strengthening activities.
- Older adults should determine their level of effort for physical activity relative to their level of fitness.
- Older adults with chronic conditions should understand whether and how their conditions affect their ability to do regular physical activity safely.
- When older adults cannot do 150 minutes of moderate-intensity aerobic activity a week because of chronic conditions, they

should be as physically active as their abilities and conditions allow.

Key Guidelines for Women During Pregnancy and the Postpartum Period

- Women 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.
- Women 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.
- Women who are pregnant should be under the care of a health care provider who can monitor the progress of the pregnancy. Women who are pregnant can consult their health care provider about whether or how to adjust their physical activity during pregnancy and after the baby is born.

Key Guidelines for Adults With Chronic Health Conditions and Adults With Disabilities

- Adults with chronic conditions or disabilities, who are able, should do 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, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Preferably, aerobic activity should be spread throughout the week.
- Adults with chronic conditions or disabilities, who are able, should also do muscle-strengthening activities of moderate or greater intensity and that involve all major muscle groups on 2 or more days a week, as these activities provide additional health benefts.
- When adults with chronic conditions or disabilities are not able to meet the above key guidelines, they should engage in regular physical activity according to their abilities and should avoid inactivity. 10 Physical Activity Guidelines for Americans
- Adults with chronic conditions or symptoms should be under the care of a health care provider. People with chronic conditions can consult a health care professional or physical activity specialist about the types and amounts of activity appropriate for their abilities and chronic conditions.

Key Guidelines for Safe Physical Activity

- To do physical activity safely and reduce risk of injuries and other adverse events, people should:
- Understand the risks, yet be confident that physical activity can be safe for almost everyone.
- Choose types of physical activity that are appropriate for their current fitness level and health goals, because some activities are safer than others.
- Increase physical activity gradually over time to meet key guidelines or health goals. Inactive people should “start low and go slow” by starting with lower intensity activities and gradually increasing how often and how long activities are done.
- Protect themselves by using appropriate gear and sports equipment, choosing safe environments, following rules and policies, and making sensible choices about when, where, and how to be active.
- Be under the care of a health care provider if they have chronic conditions or symptoms. People with chronic conditions and symptoms can consult a health care professional or physical activity specialist about the types and amounts of activity appropriate for them.

Recreational Drug Use

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

According to the U.S. Centers for Disease Control and Prevention, excessive alcohol use now contributes to roughly **178,000 deaths annually** in the United States, based on 2020–2021 data — an increase of nearly 30 percent compared to earlier years. Avoiding excessive alcohol intake reduces risks of elevated blood pressure, injury, cardiovascular disease, stroke, liver disease, and several types of cancer.

Although older studies suggested that moderate drinking might provide benefits — such as reduced risk of coronary heart disease or type 2 diabetes — more recent research and public health guidance have challenged that view. Many experts now argue there is **no safe level of alcohol consumption** for health, and that even light or moderate drinking can increase risks of cancer and other adverse outcomes. In fact, a recent federal report finds that the increased risk of dying from alcohol begins at relatively low levels of use.

Previously, U.S. dietary guidelines defined "moderate drinking" as up to one standard drink per day for women and up to two for men. However, given evolving evidence, many health authorities now emphasize that **less alcohol is better** and that zero consumption is the level that minimizes health risk.

Illicit and prescription drug abuse are associated with decreased health and is a prominent problem in the United States. The health effects of drug abuse can be far-reaching, including the increased risk of stroke, heart disease, cancer, lung disease, and liver disease[6].

Sleeping Patterns

Inadequate amounts of sleep, or not sleeping well, can also have remarkable effects on a person's health. In fact, sleeping can affect your health just as much as your diet. Scientific studies have shown that insufficient sleep increases the risk for heart disease, Type 2 diabetes, obesity, and depression. Abnormal breathing during sleep, a condition called sleep apnea, is also linked to an increased risk for chronic disease[7].

Stress Management

Our health, and food intake, is also affected by our stress levels.

Individuals handle stress differently when it comes to food. For some, stress leads them to eat mindlessly or more than they are hungry for. For others, it can cause a lack of appetite or forgetfulness around eating. For others, it has no effect on their eating, other than perhaps food choices if they don't have as much time to prepare food. Learning and practicing techniques to manage stress can improve health outcomes.

Attributions

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CHAPTER 4: PROCESSES OF LIFE — PHOTOSYNTHESIS, DIGESTION, ABSORPTION AND METABOLISM

Learning Objectives

After completing this unit, you should be able to:

1. Define and describe the levels of structural organization of the human body—from atoms and molecules to the whole organism—including the basic characteristics of cells and the organ systems.
2. Understand how photosynthesis is the pathway to glucose production and describe the relationship between photosynthesis in plants and energy metabolism in the human body.
3. Identify and briefly describe the functions of the organs of the gastrointestinal tract, and discuss the five fundamental activities of digestion, giving an example of each.
4. Describe several common disorders and discomforts of the GI tract, including their causes, symptoms, and approaches to treatment.
5. Describe food intolerances, food allergies, and celiac disease, including the different causes, symptoms, and treatments for each condition.
6. Explain the relationship between the gut microbiome, the immune system, and human health, and evaluate the current evidence linking microbiome composition to nutrition and disease, while recognizing the methodological limitations in microbiome research.

4.1: Introduction to Biomolecules

4.2: Organization of Life

4.3: Photosynthesis and Metabolism — Cellular Respiration

4.4: The Digestive System

4.4.1: Parts of the Digestive System

4.4.2: Digestive System Processes

4.4.3: Digestive System Regulation

4.5: Disorders of the GI Tract

4.6: Food Intolerances, Allergies, and Celiac Disease

4.7: The Gut Microbiome

4.8: Research Highlight - The Gut-Brain Connection

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4.1: Introduction to Biomolecules

Life is extraordinarily complex. That's true whether you're considering something as seemingly simple as a blade of grass or as obviously complicated as the human body. However, zooming in to look at the most basic elements of living things—from atoms to molecules to cells—we can start to see similarities and patterns that help us make sense of this complexity. And as we consider biological processes, such as photosynthesis, digestion, and metabolism, we also see how these processes fit together. Plants use photosynthesis to capture energy from the sun. Animals, humans included, eat the plants (or other animals that ate the plants) and use the processes of digestion and metabolism to utilize the energy they contain. In the process of energy metabolism, animals breathe out carbon dioxide, which is then used by plants for photosynthesis. It's truly a circle of life!



Figure 4.1.1: "Take a bite out of fall" by Patrick Fore on Unsplash (license information)

In this unit, we'll also zero in on the digestive system. While all organ systems relate to nutrition in some way, the digestive system takes center stage as the site of food processing and nutrient extraction. And while it usually functions as an efficient and coordinated system, we'll also consider some common ways that it can go awry, resulting in disorders and discomforts of the digestive tract or adverse reactions to certain foods.

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4.2: Organization of Life

Before you begin to study the different structures and functions of the human body related to nutrition, it is helpful to consider the basic architecture of the body; that is, how its smallest parts are assembled into larger structures. It is convenient to consider the structures of the body in terms of fundamental levels of organization that increase in complexity: atoms, molecules, cells, tissues, organs, organ systems, and organisms. Higher levels of organization are built from lower levels. Therefore, atoms combine to form molecules, molecules combine to form cells, cells combine to form tissues, tissues combine to form organs, organs combine to form organ systems, and organ systems combine to form organisms (Figure 4.2.1).

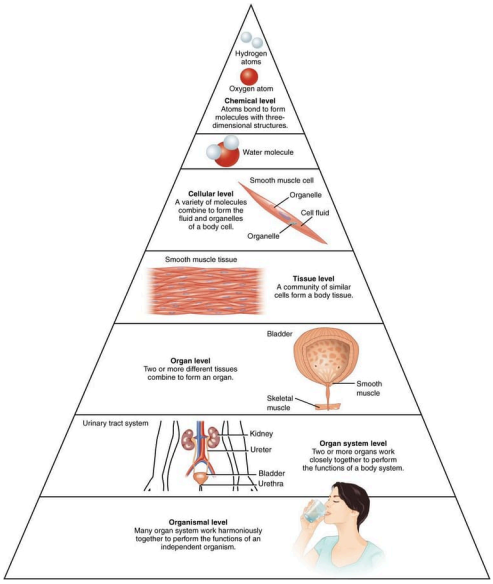


Figure 4.2.1: Levels of structural organization of the human body. The organization of the body often is discussed in terms of distinct levels of increasing complexity, from the smallest chemical building blocks to a unique human organism. ("Levels of Structural Organization of the Human Body" by OpenStax, Rice University is licensed under CC BY 4.0)

The Levels of Organization

Consider the simplest building blocks of matter: atoms and molecules. In Unit 1, you had an introduction to atoms and molecules. Remember, all matter in the universe is composed of one or more unique elements, such as hydrogen, oxygen, carbon, and nitrogen. The smallest unit of any of these elements is an atom. Atoms of individual elements combine to make molecules, and molecules bond together to make bigger macromolecules. Four macromolecules—carbohydrates, lipids, proteins, and nucleic acids (e.g., DNA, RNA)—make up all of the structural and functional units of cells.

The Basic Structural and Functional Unit of Life: The Cell

Cells are the most basic building blocks of life. All living things are composed of cells. New cells are made from preexisting cells, which divide in two. Who you are has been determined because of two cells that came together inside your mother's womb. The two cells containing all of your genetic information (DNA) fused to begin the development of a new organism. Cells divided and differentiated into other cells with specific roles that led to the formation of the body's numerous organs, systems, blood, blood vessels, bones, tissues, and skin. While all cells in an individual contain the same DNA, each cell only expresses the genetic codes that relate to that cell's specific structure and function.

As an adult, you are made up of trillions of cells. Each of your individual cells is a compact and efficient form of life—self-sufficient, yet interdependent upon the other cells within your body to supply its needs. There are hundreds of types of cells (e.g., red blood cells, nerve cells, skin cells). Each individual cell conducts all the basic processes of life. It must take in nutrients, excrete wastes, detect and respond to its environment, move, breathe, grow, and reproduce. Many cells have a short life span and have to be replaced continually. For example, enterocytes (cells that line the intestines) are replaced every 2-4 days, and skin cells are replaced every few weeks.

Although a cell is defined as the “most basic” unit of life, it is structurally and functionally complex (Figure 3.2). A human cell typically consists of a flexible outer **cell membrane** (also called a plasma membrane) that encloses ***cytoplasm***, a water-based cellular fluid, together with a variety of functioning units called ***organelles***. The organelles are like tiny organs constructed from several macromolecules bonded together. A typical animal cell contains the following organelles:

- **Nucleus**: houses genetic material (DNA)
- **Mitochondria**: often called the powerhouse of the cell, generates usable energy for the cell from energy-yielding nutrients
- **Ribosomes**: assemble proteins based on genetic code
- **Endoplasmic reticulum**: processes and packages proteins and lipids
- **Golgi apparatus** (golgi body): distributes macromolecules like proteins and lipids around the cell
- **Lysosomes**: digestive pouches which break down macromolecules and destroy foreign invaders

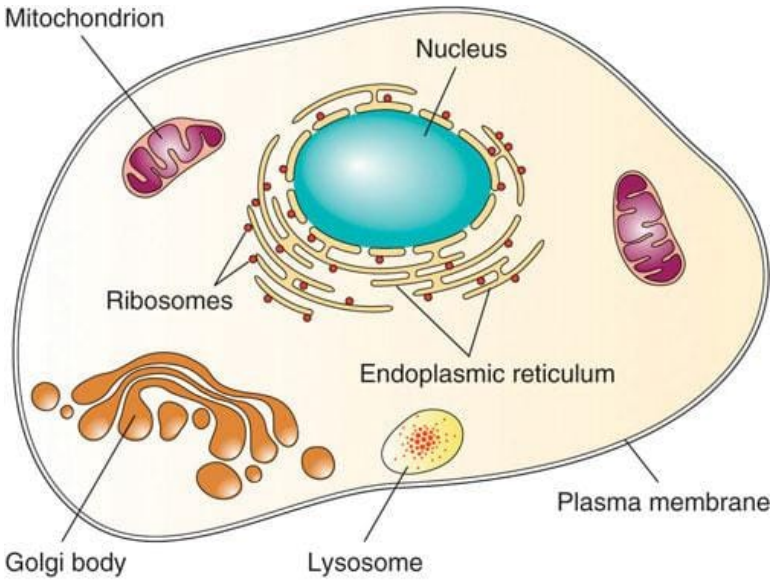


Figure 4.2.2: The cell structure. (“The Cell Structure” by University of Hawai‘i at Mānoa Food Science and Human Nutrition Program is licensed under CC BY-NC-SA 4.0)

Tissues, Organs, Organ Systems, and Organisms

A ***tissue*** is a group of many similar cells that share a common structure and work together to perform a specific function. There are four basic types of human tissues: ***connective***, which connects tissues; ***epithelial***, which lines and protects organs; ***muscle***, which contracts for movement and support; and ***nerve***, which responds and reacts to signals in the environment.

An ***organ*** is a group of similar tissues arranged in a specific manner to perform a specific physiological function. Examples include the brain, liver, and heart. An ***organ system*** is a group of two or more organs that work together to perform a specific physiological function. Examples include the digestive system and central nervous system.

There are eleven distinct organ systems in the human body (Figure 3.3). Assigning organs to organ systems can be imprecise since organs that “belong” to one system can also have functions integral to another system. In fact, many organs contribute to more than one system. And most of these organ systems are involved in nutrition-related functions within the body (Table 3.1). For example, the cardiovascular system plays a role in nutrition by transporting nutrients in the blood to the cells of the body. The endocrine system produces hormones, many of which are involved in regulating appetite, digestive processes, and nutrient levels in the blood. Even the reproductive system plays a role in providing nutrition to a developing fetus or growing baby.

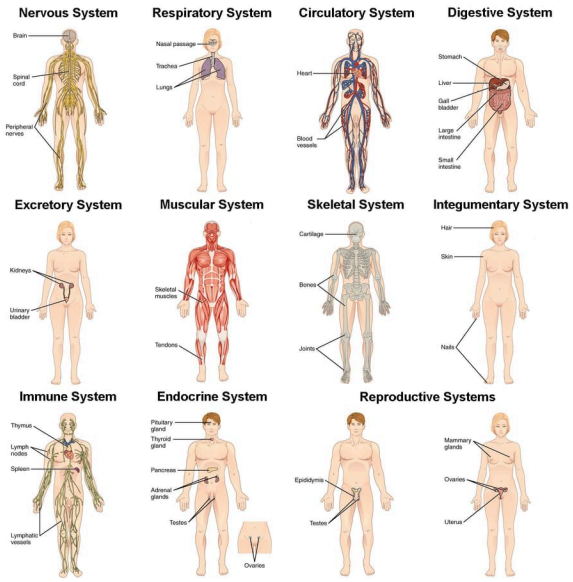


Figure 4.2.3: Organ systems of the human body ("The eleven organ systems in the human body and their major functions" by University of Hawai'i at Mānoa Food Science and Human Nutrition Program is licensed under CC BY-NC-SA 4.0)

Table 3.1. The eleven organ systems in the human body and their major functions by University of Hawai'i at Mānoa Food Science and Human Nutrition Program is licensed under CC BY-NC-SA 4.0

Organ System	**Major Organ Components**	**Major Functions**
Cardiovascular	Heart, blood/lymph vessels, blood, lymph	Transport oxygen, nutrients, and waste products
Digestive	Mouth, esophagus, stomach, intestines, salivary glands, pancreas, liver and gallbladder	Digestion and absorption
Endocrine	Endocrine glands (e.g., thyroid, ovaries, pancreas)	Produce and release hormones, regulate nutrient levels
Immune	White blood cells, lymphatic tissue, marrow	Defend against foreign invaders
Integumentary	Skin, nails, hair, sweat glands	Protection, body temperature regulation
Muscular	Skeletal, smooth, and cardiac muscle	Body movement
Nervous	Brain, spinal cord, nerves	Interpret and respond to stimuli, appetite control

Reproductive	Gonads, genitals	Reproduction and sexual characteristics
Respiratory	Lungs, nose, mouth, throat, trachea	Gas exchange (oxygen and carbon dioxide)
Skeletal	Bones, tendons, ligaments, joints	Structure and support, calcium storage
Urinary/ Excretory	Kidneys, bladder, ureters	Waste excretion, water balance

An ***organism*** is the highest level of organization—a complete living system capable of conducting all of life's biological processes. In multicellular organisms, including humans, all cells, tissues, organs, and organ systems of the body work together to maintain the life and health of the organism.

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- Figure 3.2. "Organ Systems of the Human Body" by OpenStax, Rice University is licensed under CC BY 4.0
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4.3: Photosynthesis and Metabolism — Cellular Respiration

As we just learned in the previous section, cells are the most basic building blocks of life. Cells make up your tissues, organs, and ultimately, you as a human being. And every one of those cells needs energy to perform their specific functions. Where does that energy come from? It comes from the macronutrients that we eat—carbohydrates, protein, and fat. In order to understand how the cells of the body put that energy to use, you must have a basic understanding of photosynthesis, cellular respiration, and the relationship between these two processes.

Photosynthesis

Photosynthesis is essential to all life on earth; both plants and animals depend on it. It is the only biological process that can capture energy that originates from sunlight and convert it into a chemical compound (glucose) that every organism uses to power its daily functions. Photosynthesis is also a source of oxygen necessary for many living organisms.



Figure 4.3.1: Green leafed plant in sunlight by Vlad Kutepov on Unsplash (license information)

The importance of photosynthesis is not just that it can capture sunlight's energy. Photosynthesis is vital because it provides a way to capture the energy from solar radiation (the "photo-" part) and store that energy in the carbon-carbon bonds of glucose (the "-synthesis" part). Glucose is the main energy source that animals and humans use to power the synthesis of ***adenosine triphosphate (ATP)***. ATP is the energy-containing molecule found in the cells of all animals and humans. Energy from the foods we eat is captured in ATP and used to fuel the workload of cells.[1]

The energy stored in carbohydrate molecules from photosynthesis passes through the food chain. Consider a predator, such as a wolf, preying on a deer. The wolf is at the end of an energy path that went from atoms colliding on the surface of the sun, to visible light, to photosynthesis, to vegetation, to the deer, and finally to the wolf. The wolf, by feeding on the deer, receives a portion of the energy that originated in the photosynthetic vegetation that the deer consumed.

Our food supply is also directly linked to photosynthesis. Major grocery stores in the United States are organized into departments, such as dairy, meats, produce, bread, cereals, and so forth. Each aisle contains hundreds, if not thousands, of different products for customers to buy and consume. Although there is a large variety, each item ultimately can be linked back to photosynthesis. Meat and dairy link because the animals were fed plant-based foods. The breads, cereals, and pastas come largely from starchy grains, which are the seeds of photosynthesis-dependent plants. What about desserts and drinks? All of these products contain sugar—sucrose is a plant product, a carbohydrate molecule, which is also derived from photosynthesis. Many items are less obviously derived from plants: virtually every spice and flavoring in the spice aisle was produced by a plant as a leaf, root, bark, flower, fruit, or stem. (Salt is a notable exception.) Ultimately, photosynthesis connects to every meal and every food a person consumes.

Main Structures and Summary of Photosynthesis

Photosynthesis generally takes place in the leaves of plants. It is a multi-step process that requires sunlight, carbon dioxide (CO_2, found in the air), and water (H_2O, from the soil). After the process is complete, the plant releases oxygen into the air (O_2, essential for many living organisms) and produces the simple carbohydrate molecule of glucose, which can be used as an energy source by the plant, converted to starch and stored for a later energy source, or converted into other organic molecules such as fats, proteins and vitamins. This glucose contains the energy that all living organisms need to survive.

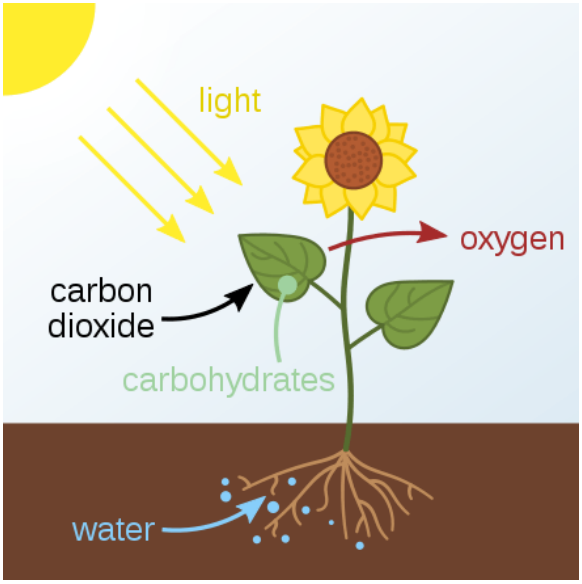


Figure 4.3.2: Depiction of photosynthesis in plants. The carbohydrates produced are stored in or used by the plant. ("Depiction of photosynthesis in plants" by Nefronus is licensed under CC BY-SA 4.0)

The basic formula for photosynthesis is as follows:

$$6\,CO_2 + 6\,H_2O + \text{sun's energy} = C_6H_{12}O_6 + 6\,O_2 \tag{4.3.1}$$

6 CO_2 + 6 H_2O + sun's energy = $C_6H_{12}O_6$ + 6 O_2

Another way of saying this:

Photosynthesis uses:	6 molecules of carbon dioxide ($6CO_2$) 6 molecules of water ($6H_2O$) the sun's energy
Photosynthesis produces:	1 molecule of glucose ($C_6H_{12}O_6$) 6 molecules of oxygen ($6O_2$)

Starch is the storage form of glucose in plants, stored in seeds, roots, and tubers for later use as an energy source for the plant to reproduce. When a seed is buried deep in the soil, this starch can be broken down into glucose to be used for energy for the seed to sprout. As the seed sprouts, and shoots go above the ground and leaves start to form, the new plant can then photosynthesize glucose for an energy source. When we eat foods that contain starch, we must digest that starch down into single sugars (glucose) in order for the glucose to be absorbed into the intestinal cells, where it will enter the bloodstream to be carried to all cells of the body to use as an energy source. The basic process of digestion of these foods will be covered in the next section.

Cellular Respiration

All living things require energy to survive. For humans, and many other organisms, that energy is generated by the complex interaction of photosynthesis and ***cellular respiration***. Cellular respiration is a key pathway in ***energy metabolism*** (the process of converting food into energy) of all aerobic organisms. ***Respiration*** refers to breathing: taking in oxygen and removing carbon dioxide. But ultimately, the reason we need to breathe is to provide the oxygen needed to carry out cellular respiration in our cells and to remove the carbon dioxide that is produced as a byproduct.

In the process of cellular respiration, energy that is stored in the food we eat is converted to the body's energy currency, ATP, while a small amount is lost as heat. During cellular respiration, glucose is broken down to carbon dioxide and water; in the process, ATP is released. **Cellular respiration occurs in the mitochondria of cells and is an aerobic process, which means that oxygen is required**. It is a series of reactions that can be summarized as follows:

$$\text{glucose} + 6\,O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + \text{energy (ATP and heat)} \tag{4.3.2}$$

Another way of saying this:

Cellular respiration uses:	1 molecule of glucose ($C_6H_{12}O_6$) 6 molecules of oxygen ($6O_2$)
Cellular respiration produces:	6 molecules of carbon dioxide ($6CO_2$) 6 molecules of water ($6H_2O$) Energy

Even though glucose is the starting substance used in cellular respiration, we do not consume only glucose as an energy source. Instead, many different kinds of food molecules are broken down into smaller molecules, metabolized, and then enter the cellular respiration pathway. For example, complex carbohydrates like starch are readily converted to glucose. Fats and proteins can also be used in cellular respiration, but they must be modified before they can feed into the process.

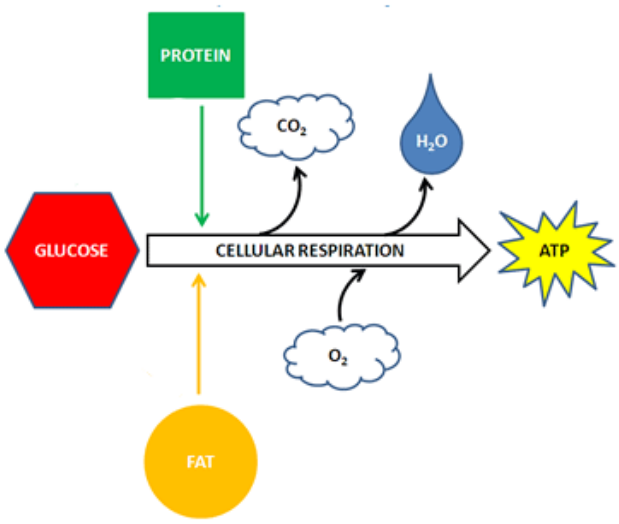


Figure 4.3.3: Nutrients fuel cellular respiration. Other carbohydrates, like starch and sugars, are converted to glucose before entering cellular respiration. ("Fuels feed into cellular respiration" by Introduction to Biology is licensed under CC BY-NC-SA 3.0)

Photosynthesis-Cellular Respiration Cycle

If you compare the summary reactions of photosynthesis and cellular respiration, you can see that cellular respiration is the opposite of photosynthesis. Because each process starts where the other ends, they form a cycle. What one reaction uses, the other reaction produces, and what one produces the other uses.

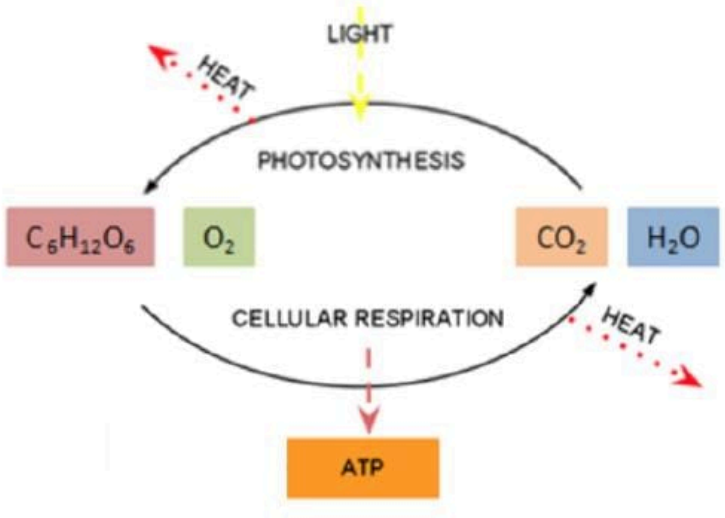


Figure 4.3.4: The relationship between the reactions of photosynthesis and cellular respiration. ("The relationship between the reactions of photosynthesis and cellular respiration" by Heather Leonard is licensed under CC BY-NC-SA 3.0 / A derivative from the original work)

The cycling that occurs between photosynthesis and cellular respiration is vital to the health of planet Earth. If there was no way for the carbon dioxide produced through cellular respiration to be utilized, breathing organisms (like humans and animals) would soon suffocate. Additionally, photosynthetic organisms are at the base of almost every food chain on the planet, so without these organisms, mass starvation would result. Luckily, this planet is full of organisms capable of photosynthesis (e.g., trees and grass on land and algae and bacteria in the ocean). Without this vital connection between photosynthesis and cellular respiration, life as we know it would cease to exist.

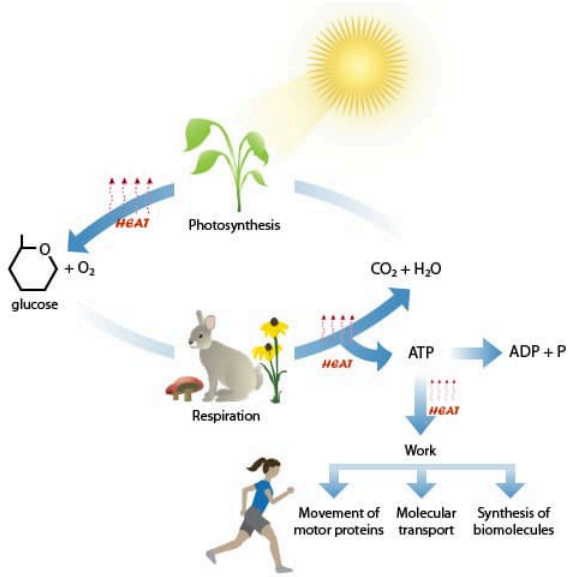


Figure 4.3.5: The photosynthesis-cellular respiration cycle. The two processes are intimately linked. (The photosynthesis-cellular respiration cycle" by Introduction to Biology is licensed under CC BY-NC-SA 3.0)

YouTube Video

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Video 4.3.1: In this animation, cellular respiration and its connection to photosynthesis are explained, with metabolism of glucose shared as an example https://youtu.be/4Eo7JtRA7lg

Attributions

- Rice University, "Overview of Photosynthesis" by Mary Ann Clark, Matthew Douglas, Jung Choi, Biology 2e, OpenStax is licensed under CC BY 4.0
- "Metabolism", Introduction to Biology is licensed under CC BY-NC-SA 3.0

References:

- [1]Adenosine Triphosphate. (n.d.) Encyclopaedia Britannica. https://www.britannica.com/science/adenosine-triphosphate

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4.4: The Digestive System

We just learned that our body is composed of billions of cells. To function, these cells need essential nutrients—carbohydrates, proteins, fats, vitamins, and minerals—which we obtain from foods. However, before our cells can access these nutrients, foods need to be broken down or digested into their simplest units, so that the nutrients can be absorbed and enter the bloodstream. Digestion is a complex process that involves many organs and chemicals, as we'll explore on this page.

The video below provides a visual journey through the process, serving as a dynamic companion to the information presented in the text that follows.

YouTube Video

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Video 4.4.1: How Your Digestive System Works by Emma Bryce, Ted-Ed (Dec 14, 2017). 4:56 minutes.

An Overview of the Organs Involved in Digestion

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

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

- The ***GI tract*** is a one-way tube about 25 feet in length, beginning at the mouth and ending at the anus. Between these two points, the GI tract also contains the pharynx, esophagus, stomach, small and large intestines, and the rectum. The small intestine is comprised of three parts: the duodenum, the jejunum, and the ileum. The large intestine, also called the colon, is similarly divided into three sections: the ascending colon, transverse colon, and descending colon. Both the mouth and anus are open to the external environment; thus, food and wastes within the GI tract are technically considered to be outside the body. Only through the process of absorption do the nutrients in food enter into and nourish the body's "inner space."

- ***Accessory organs***, despite their name, are critical to the function of the digestive system. They are considered accessory organs since they are not actually part of the intestinal tract itself, but have ducts that deliver digestive juices into the tract to help aid in digestion. There are four accessory organs: the salivary glands, liver, gallbladder, and pancreas. All of these organs secrete fluids containing a variety of chemicals such as enzymes and acids that aid in digestion.

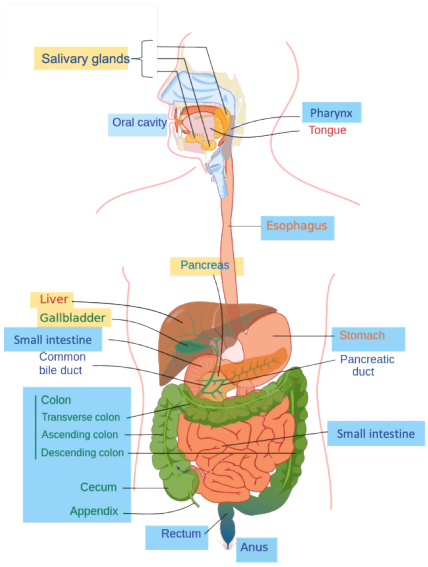


Figure 4.4.1: An overview of the organs involved in digestion. The parts of the GI tract are highlighted in blue, and the accessory organs are highlighted in yellow. ("GI tract and accessory organs" by Alice Callahan is licensed under CC BY 4.0; edited from "Digestive system diagram edit" by Mariana Ruiz, edited by Joaquim Alves Gaspar, Jmarchn is in the Public Domain)

An Overview of the Digestive Process

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

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

Food (now called a ***bolus*** since it has been chewed and moistened) leaves the mouth when the tongue and pharyngeal muscles propel the bolus into the esophagus. The bolus will travel down the esophagus through an involuntary process called peristalsis. ***Peristalsis*** consists of sequential, alternating waves of contraction and relaxation of the smooth muscles in the GI tract, which act to propel food along (Figure 3.10). These waves also play a role in mixing food with digestive juices. Peristalsis is so powerful that foods and liquids you swallow enter your stomach even if you are standing on your head.

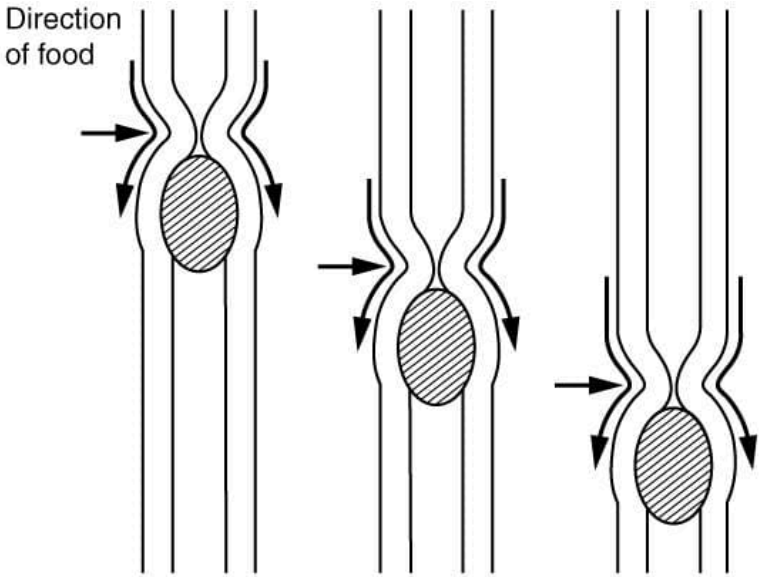


Figure 4.4.2: Peristalsis moves food through the digestive tract with alternating waves of muscle contraction and relaxation. ("Peristalsis" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix, Anatomy and Physiology, OpenStax, licensed under CC BY 4.0)

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

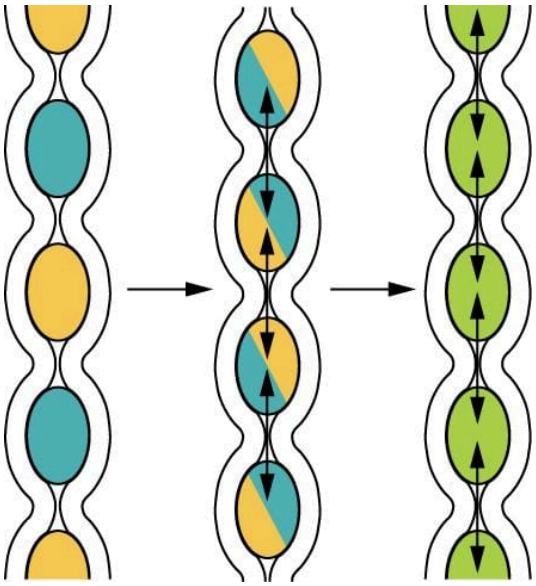


Figure 4.4.3: Segmentation separates chyme and then pushes it back together, mixing it and providing time for digestion and absorption. ("Segmentation" by OpenStax College is licensed under CC BY 3.0)

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

sugars), before it can be absorbed. This breakdown happens through hydrolysis, and the enzyme, sucrase, brings together the sucrose molecule and the water molecule to react. This process is illustrated in the following animation.

YouTube Video

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

View this YouTube Video online

Video 4.4.1: Enzyme Action and the Hydrolysis of Sucrose by McGraw-Hill Animations, YouTube (June 3, 2017). 1:46 minutes.

Nutrients are of little to no value to the body unless they enter the bloodstream. This occurs through the process of ***absorption***, which takes place primarily within the small intestine. There, most nutrients are absorbed from the ***lumen*** (or inside space) of the GI tract into the bloodstream. Lipids are absorbed into lymph but eventually enter the bloodstream as well.

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

Functions of the Digestive Organs

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

Mouth

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

Esophagus

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

Stomach

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

When the peanut butter and jelly sandwich enters the stomach, a highly muscular organ, powerful peristaltic contractions help mash, pulverize, and churn it into chyme. ***Chyme*** is a semiliquid mass of partially digested food along with gastric juices secreted

by cells in the stomach. These gastric juices contain ***hydrochloric acid***, which lowers the pH of the chyme in the stomach. This acidic environment kills many bacteria or other germs that may have been present in the food, and it causes the three-dimensional structure of dietary proteins to unfold. Gastric juices also contain the enzyme ***pepsin***, which begins the chemical breakdown of proteins in the peanut butter and bread. ***Gastric lipase*** continues the breakdown of fat from the peanut butter.

Small Intestine

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

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

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

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

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

The small intestine is perfectly structured for maximizing nutrient absorption. Its surface area is greater than 200 square meters—about the size of a tennis court! The large surface area is due to the multiple levels of folding, villi, and microvilli that cover the internal tissue of the small intestine. ***Villi*** are tiny finger-like projections that are covered with ***enterocytes*** or absorptive cells. The absorptive cell membrane is made of even smaller projections, called ***microvilli*** (Figure 3.12). These microvilli are referred to collectively as the ***brush border*** since their appearance resembles the bristles on a brush.

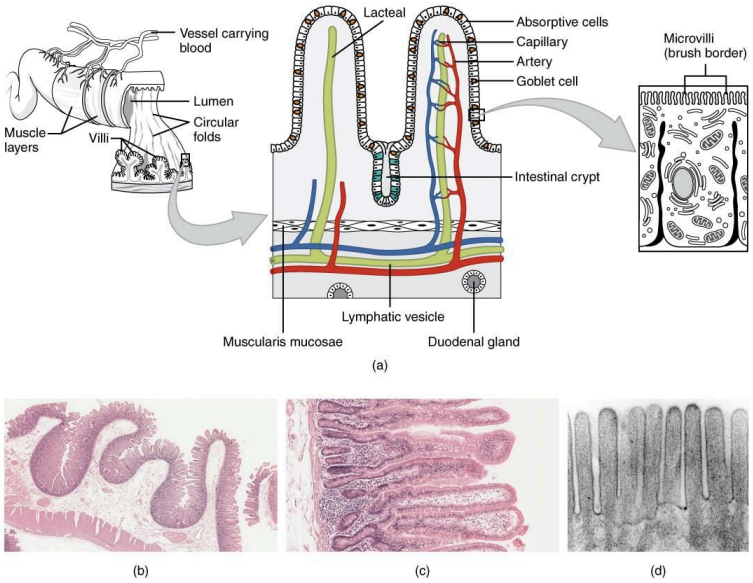


Figure 4.4.4: istology of the small intestine. (a) The absorptive surface of the small intestine is vastly enlarged by the presence of circular folds, villi, and microvilli. (b) Micrograph of the circular folds. (c) Micrograph of the villi. (d) Electron micrograph of the microvilli. ("Histology Small Intestines" by OpenStax College is licensed under CC BY 3.0)

Digested nutrients are absorbed into either capillaries or lymphatic vessels contained within each villus. Amino acids (from protein digestion), small fatty acids (from triglyceride digestion), sugars (from carbohydrate digestion), water-soluble vitamins, and minerals are transported from the intestinal cells into the bloodstream through capillaries. The larger fatty acids, fat-soluble vitamins, and other lipids (that are packaged in lipid transport particles) are transported first through lymphatic vessels and then

eventually meet up with the blood. Water-soluble nutrients that enter the bloodstream are transported directly to the liver where the liver processes, stores, or releases these nutrients to other body cells.

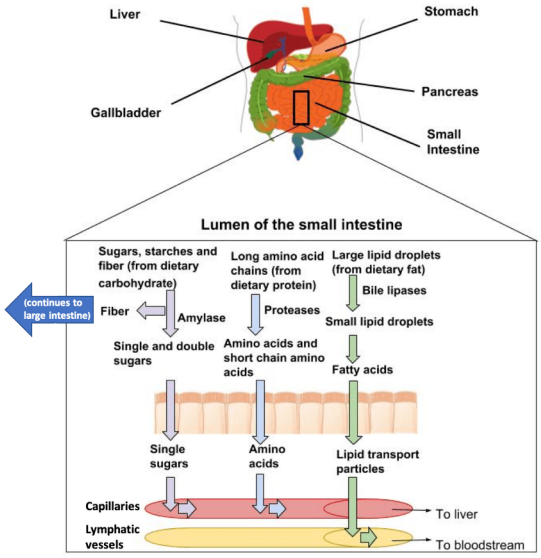


Figure 4.4.5: The digestion and absorption of nutrients in the small intestine. (“Absorption of Nutrients” by Tamberly Powell is licensed under CC BY 4.0; edited from University of Hawai‘i at Mānoa Food Science and Human Nutrition Program, “The Digestive System,” CC BY-NC 4.0)

Large Intestine

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

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

The figure below summarizes the functions of the digestive organs.

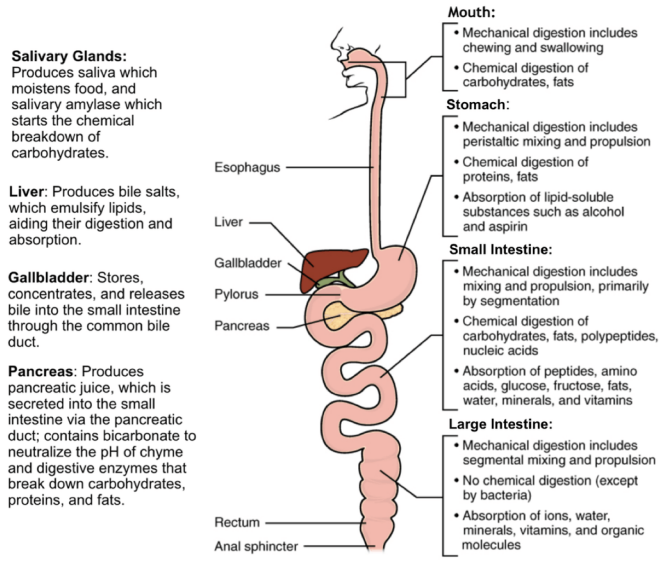


Figure 4.4.6: Summary of digestion and absorption. Digestion begins in the mouth and continues as food travels through the small intestine. Most absorption occurs in the small intestine. ("Functions of the Digestive Organs" by Tamberly Powell is licensed under CC BY 4.0; edited from "Figure 23.28 Digestion and Absorption" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix , Anatomy and Physiology, OpenStax, licensed under CC BY 4.0)

YouTube Video

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Video 4.4.7: The Digestive System by National Geographic, YouTube (November 26, 2012), 5:07 minutes.

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4.4.1: Parts of the Digestive System

Learning Objectives

Describe how food moves through the digestive system.

Explain the functions of the organs, muscles, and digestive secretions that are involved in the digestion and absorption of food.

Oral Cavity

The oral cavity, or mouth, is the point of entry of food into the digestive system. The food consumed is broken into smaller particles by mastication, the chewing action of the teeth.

The extensive chemical process of digestion begins in the mouth. As food is being chewed, saliva, produced by the salivary glands, mixes with the food. Saliva is a watery substance produced in the mouth. There are three major glands that secrete saliva—the parotid, the submandibular, and the sublingual. Saliva contains mucus that moistens food and buffers the pH of the food. Saliva also contains immunoglobulins and lysozymes, which have antibacterial action to reduce tooth decay by inhibiting growth of some bacteria. Saliva also contains an enzyme called **salivary amylase** that begins the process of converting starches in the food into a disaccharide called maltose. Another enzyme called **lipase** is produced by the cells in the tongue. Lipases are a class of enzymes that can breakdown triglycerides. The lingual lipase begins the breakdown of fat components in the food. The chewing and wetting action provided by the teeth and saliva prepare the food into a mass called the **bolus** for swallowing. The tongue helps in swallowing—moving the bolus from the mouth into the pharynx. The pharynx opens to two passageways: the trachea, which leads to the lungs, and the esophagus, which leads to the stomach. The trachea has an opening called the glottis, which is covered by a cartilaginous flap called the epiglottis. When swallowing, the epiglottis closes the glottis and food passes into the esophagus and not the trachea. This arrangement allows food to be kept out of the trachea.

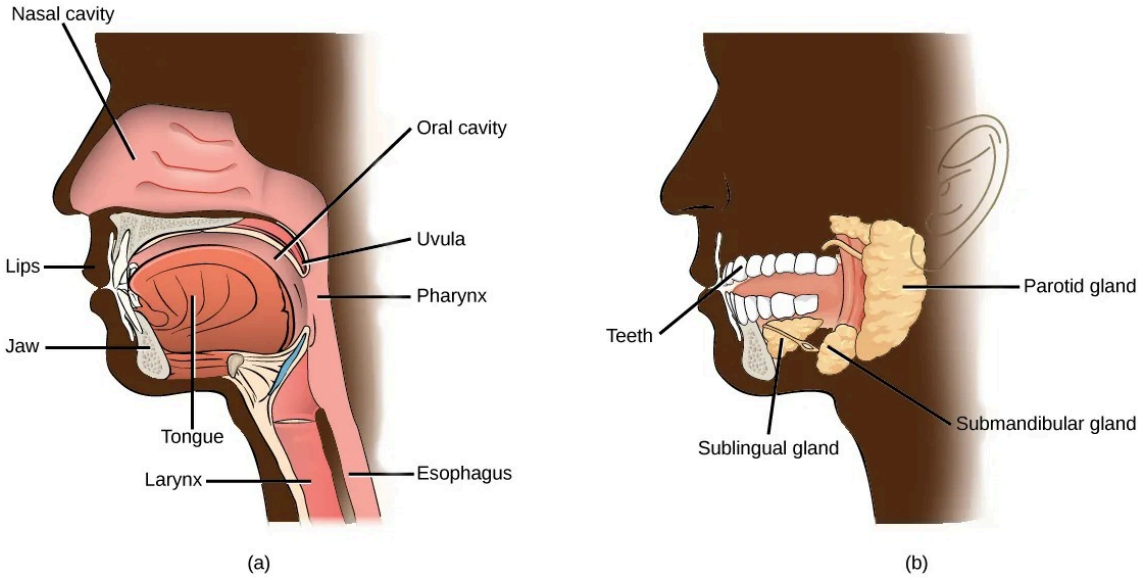


Figure \(\PageIndex{1}\): Digestion of food begins in the (a) oral cavity. Food is masticated by teeth and moistened by saliva secreted from the (b) salivary glands. Enzymes in the saliva begin to digest starches and fats. With the help of the tongue, the resulting bolus is moved into the esophagus by swallowing. Image from Openstax Biology 2e, modification of work by the National Cancer Institute / CC BY 4.0

Esophagus

The **esophagus** is a tubular organ that connects the mouth to the stomach. The chewed and softened food passes through the esophagus after being swallowed. The smooth muscles of the esophagus undergo a series of wave like movements called **peristalsis** that push the food toward the stomach. The peristalsis wave is unidirectional—it moves food from the mouth to the stomach, and reverse movement is not possible. The peristaltic movement of the esophagus is an involuntary reflex; it takes place in response to the act of swallowing.

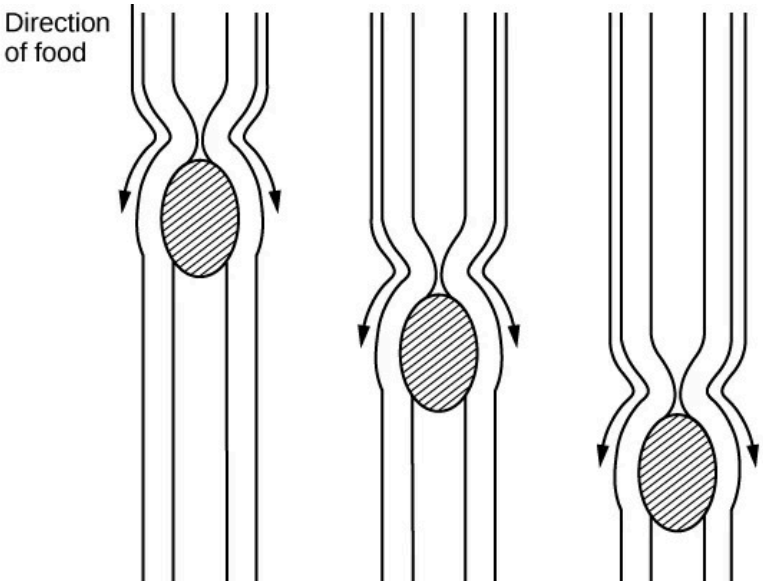


Figure 4.4.1.2: The esophagus transfers food from the mouth to the stomach through peristaltic movements. Image from Openstax Biology 2e / CC BY 4.0

A ring-like muscle called a **sphincter** forms valves in the digestive system. The gastro-esophageal sphincter is located at the stomach end of the esophagus. In response to swallowing and the pressure exerted by the bolus of food, this sphincter opens, and the bolus enters the stomach. When there is no swallowing action, this sphincter is shut and prevents the contents of the stomach from traveling up the esophagus. Acid reflux or “heartburn” occurs when the acidic digestive juices escape into the esophagus.

Stomach

A large part of digestion occurs in the stomach. The **stomach** is a saclike organ that secretes gastric digestive juices. The pH in the stomach is between 1.5 and 2.5. This highly acidic environment is required for the chemical breakdown of food and the extraction of nutrients. When empty, the stomach is a rather small organ; however, it can expand to up to 20 times its resting size when filled with food.

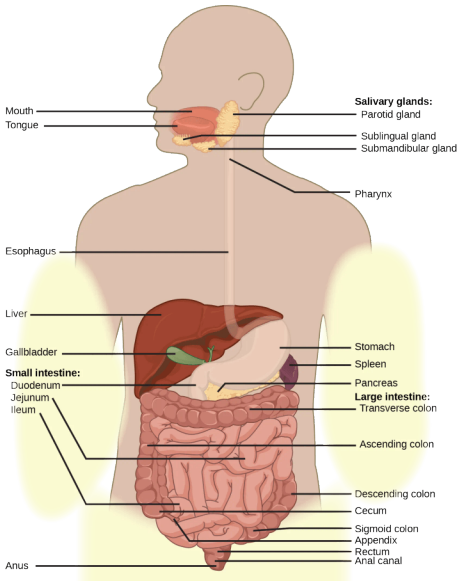


Figure 4.4.1.3: The human stomach has an extremely acidic environment where most of the protein gets digested. Image from Openstax Biology 2e, modification of work by Mariana Ruiz Villareal / CC BY 4.0

The stomach is also the major site for protein digestion. Protein digestion is mediated by an enzyme called pepsin in the stomach. **Pepsin** is secreted by the chief cells in the stomach in an inactive form called **pepsinogen**. Pepsin breaks peptide bonds and cleaves proteins into smaller polypeptides; it also helps activate more pepsinogen, starting a positive feedback mechanism that generates more pepsin. Another cell type—parietal cells—secrete hydrogen and chloride ions, which combine in the lumen to form hydrochloric acid, the primary acidic component of the stomach juices. Hydrochloric acid helps to convert the inactive pepsinogen to pepsin. The highly acidic environment also kills many microorganisms in the food and, combined with the action of the enzyme pepsin, results in the hydrolysis of protein in the food. Chemical digestion is facilitated by the churning action of the stomach. Contraction and relaxation of smooth muscles mixes the stomach contents about every 20 minutes. The partially digested food and gastric juice mixture is called **chyme**. Chyme passes from the stomach to the small intestine. Further protein digestion takes place in the small intestine. Gastric emptying occurs within two to six hours after a meal. Only a small amount of chyme is released into the small intestine at a time. The movement of chyme from the stomach into the small intestine is regulated by the pyloric sphincter.

When digesting protein and some fats, the stomach lining must be protected from getting digested by pepsin. There are two points to consider when describing how the stomach lining is protected. First, as previously mentioned, the enzyme pepsin is synthesized in the inactive form. This protects the chief cells, because pepsinogen does not have the same enzyme functionality of pepsin. Second, the stomach has a thick mucus lining that protects the underlying tissue from the action of the digestive juices. When this mucus lining is ruptured, ulcers can form in the stomach. Ulcers are open wounds in or on an organ caused by bacteria (*Helicobacter pylori*) when the mucus lining is ruptured and fails to reform.

Small Intestine

Chyme moves from the stomach to the small intestine. The **small intestine** is the organ where the digestion of protein, fats, and carbohydrates is completed. The small intestine is a long tube-like organ with a highly folded surface containing finger-like projections called the **villi**. The surface of each villus has many microscopic projections called microvilli. These structures are lined with epithelial cells on the luminal side and allow for the nutrients to be absorbed from the digested food and absorbed into the bloodstream on the other side. The villi and microvilli, with their many folds, increase the surface area of the intestine and increase absorption efficiency of the nutrients. Absorbed nutrients in the blood are carried into the hepatic portal vein, which leads to the liver. There, the liver regulates the distribution of nutrients to the rest of the body and removes toxic substances, including drugs, alcohol, and some pathogens.

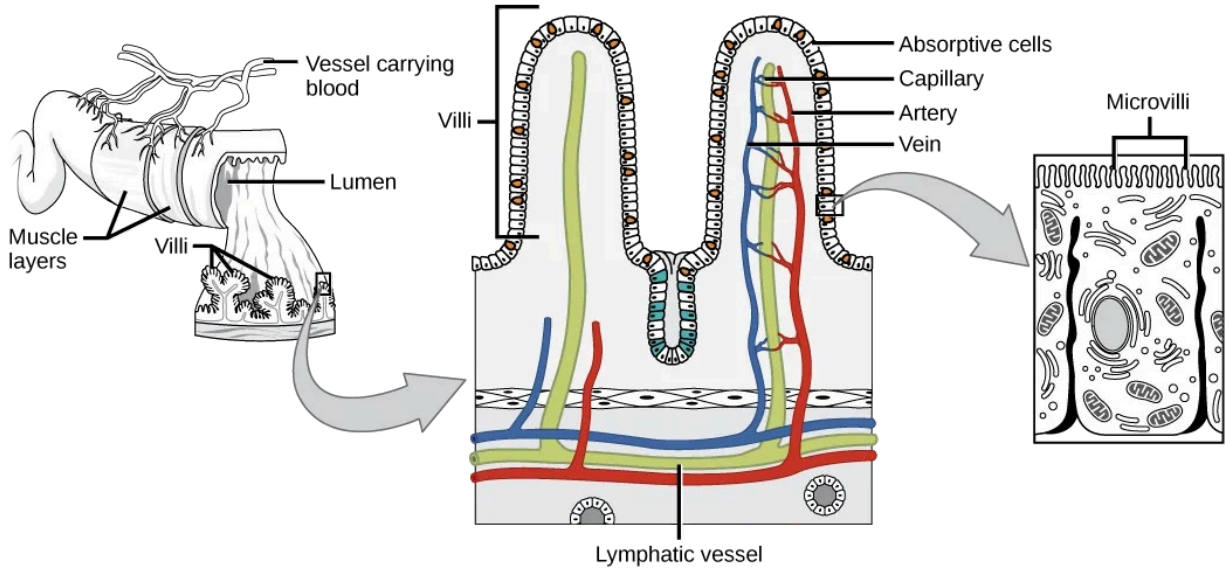


Figure 4.4.1.4: Villi are folds on the small intestine lining that increase the surface area to facilitate the absorption of nutrients. Image from Openstax Biology 2e / CC BY 4.0

The human small intestine is over 6m long and is divided into three parts: the duodenum, the jejunum, and the ileum. The "C-shaped," fixed part of the small intestine is called the **duodenum**. The duodenum is separated from the stomach by the pyloric sphincter which opens to allow chyme to move from the stomach to the duodenum. In the duodenum, chyme is mixed with pancreatic juices in an alkaline solution rich in bicarbonate that neutralizes the acidity of chyme and acts as a buffer. Pancreatic juices also contain several digestive enzymes. Digestive juices from the pancreas, liver, and gallbladder, as well as from gland cells of the intestinal wall itself, enter the duodenum. **Bile** is produced in the liver and stored and concentrated in the gallbladder. Bile contains bile salts which emulsify lipids while the pancreas produces enzymes that catabolize starches, disaccharides, proteins, and fats. These digestive juices breakdown the food particles in the chyme into glucose, triglycerides, and amino acids. Some chemical digestion of food takes place in the duodenum. Absorption of fatty acids also takes place in the duodenum.

The second part of the small intestine is called the **jejunum**. Here, hydrolysis of nutrients is continued while most of the carbohydrates and amino acids are absorbed through the intestinal lining. The bulk of chemical digestion and nutrient absorption occurs in the jejunum.

The **ileum** is the last part of the small intestine and here the bile salts and vitamins are absorbed into the bloodstream. The undigested food is sent to the colon from the ileum via peristaltic movements of the muscle. The ileum ends and the large intestine begins at the ileocecal valve. The vermiform, "worm-like," appendix is located at the ileocecal valve. The appendix of humans secretes no enzymes and has an insignificant role in immunity.

Large Intestine

The **large intestine** reabsorbs the water from the undigested food material and processes the waste material. The human large intestine is much smaller in length compared to the small intestine but larger in diameter. It has three parts: the cecum, the colon, and the rectum. The cecum joins the ileum to the colon and is the receiving pouch for the waste matter. The colon is home to many bacteria or "intestinal flora" that aid in the digestive processes. The colon can be divided into four regions, the ascending colon, the transverse colon, the descending colon, and the sigmoid colon. The main functions of the colon are to extract the water and mineral salts from undigested food, and to store waste material.

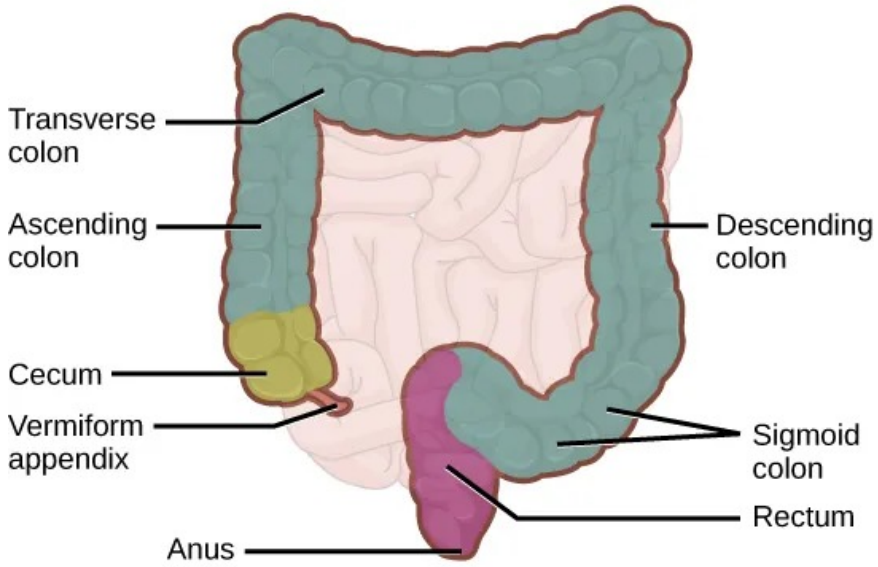


Figure 4.4.1.5: The large intestine reabsorbs water from undigested food and stores waste material until it is eliminated. Image from Openstax Biology 2e / CC BY 4.0

Rectum and Anus

The **rectum** is the terminal end of the large intestine. The primary role of the rectum is to store the feces until defecation. The feces are propelled using peristaltic movements during elimination. The **anus** is an opening at the far-end of the digestive tract and is the exit point for the waste material. Two sphincters between the rectum and anus control elimination: the inner sphincter is involuntary and the outer sphincter is voluntary.

Accessory Organs

The organs discussed above are the organs of the digestive tract through which food passes. Accessory organs are organs that add secretions (enzymes) that catabolize food into nutrients. Accessory organs include salivary glands, the liver, the pancreas, and the gallbladder. The liver, pancreas, and gallbladder are regulated by hormones in response to the food consumed.

The **liver** is the largest internal organ in humans and it plays a very important role in digestion of fats and detoxifying blood. The liver produces bile, a digestive juice that is required for the breakdown of fatty components of the food in the duodenum. The liver also processes the vitamins and fats and synthesizes many blood proteins.

The **pancreas** is another important gland that secretes digestive juices. The chyme produced from the stomach is highly acidic in nature; the pancreatic juices contain high levels of bicarbonate, an alkali that neutralizes the acidic chyme. Additionally, the pancreatic juices contain a large variety of enzymes that are required for the digestion of protein and carbohydrates.

The **gallbladder** is a small organ that aids the liver by storing bile and concentrating bile salts. When chyme containing fatty acids enters the duodenum, the bile is secreted from the gallbladder into the duodenum.

Table : 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

Organ	Major functions
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 breakdown of complex macromolecules in foods to simple absorbable components is accomplished by the digestive system. These components are processed by cells throughout the body into energy or are used as building blocks.
- 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.

Attributions

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Functions of the Digestive Organs table and Key Takeaways from Introduction to Nutrition (Diker). Accessed December 13, 2020. Available at https://med.libretexts.org/Courses/Metropolitan_State_University_of_Denver/Introduction_to_Nutrition_(Diker)/03%3A_Digestion/3.02%3A_Digestion_and_Absorption

Edited by Christine Bisson

Learning Check 4.4.1.1

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4.4.2: Digestive System Processes

Learning Objectives

- Describe the process of digestion
- Detail the steps involved in digestion and absorption
- Define elimination
- Explain the role of both the small and large intestines in absorption

Ingestion

Obtaining nutrition and energy from food is a multistep process. The large molecules found in intact food cannot pass through the cell membranes. Food needs to be broken into smaller particles so that animals can harness the nutrients and organic molecules. The first step in this process is **ingestion**. Ingestion is the process of taking in food through the mouth. The teeth, saliva, and tongue play important roles in mastication (chewing and forming the food into a bolus to be swallowed). While the food is being mechanically broken down, the enzymes in saliva begin to chemically process the food as well. The combined action of these processes modifies the food from large particles to a soft mass that can be swallowed and can travel the length of the esophagus.

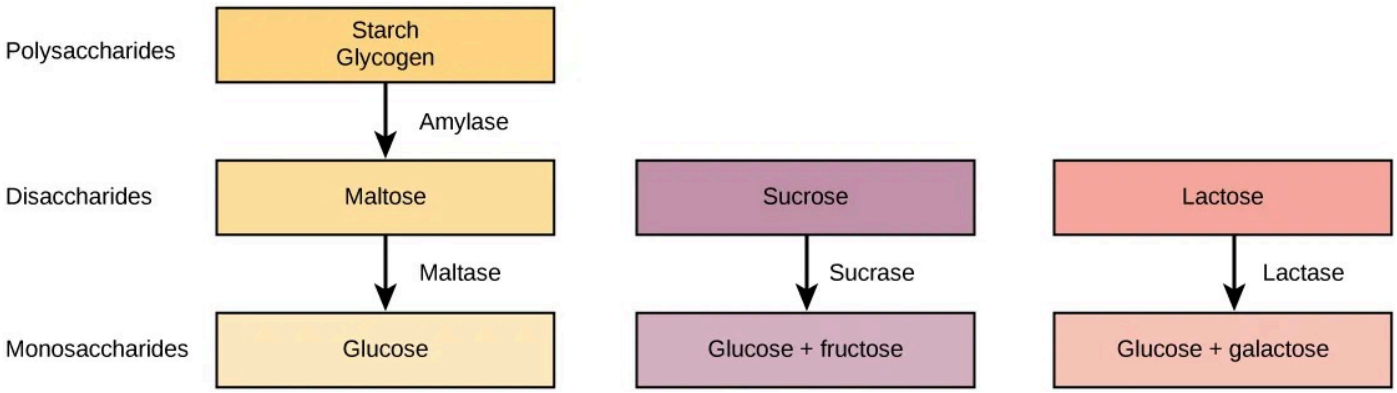
Digestion and Absorption

Digestion is the mechanical and chemical breakdown of food into small organic fragments. It is important to breakdown macromolecules into smaller fragments that are of suitable size for absorption across the digestive epithelium. Large, complex molecules of proteins, polysaccharides, and lipids must be reduced to simpler particles such as simple sugar before they can be absorbed by the digestive epithelial cells. Different organs play specific roles in the digestive process. The human diet needs carbohydrates, protein, and fat, as well as vitamins and inorganic components for nutritional balance. How each of these components is digested is discussed in the following sections.

Carbohydrates

The digestion of carbohydrates begins in the mouth. The salivary enzyme amylase begins the breakdown of food starches into maltose, a disaccharide. As the bolus of food travels through the esophagus to the stomach, no significant digestion of carbohydrates takes place. The esophagus produces no digestive enzymes but does produce mucous for lubrication. The acidic environment in the stomach stops the action of the amylase enzyme.

The next step of carbohydrate digestion takes place in the duodenum. Recall that the chyme from the stomach enters the duodenum and mixes with the digestive secretion from the pancreas, liver, and gallbladder. Pancreatic juices also contain amylase, which continues the breakdown of starch and glycogen into maltose, a disaccharide. The disaccharides are broken down into monosaccharides by enzymes called **maltases**, **sucrases**, and **lactases**, which are also present in the brush border of the small intestinal wall. Maltase breaks down maltose into glucose. Other disaccharides, such as sucrose and lactose are broken down by sucrase and lactase, respectively. Sucrase breaks down sucrose (or “table sugar”) into glucose and fructose, and lactase breaks down lactose (or “milk sugar”) into glucose and galactose. The monosaccharides (glucose) thus produced are absorbed and then can be used in metabolic pathways to harness energy. The monosaccharides are transported across the intestinal epithelium into the bloodstream to be transported to the different cells in the body.



Digestion of Carbohydrates

Enzyme	Produced By	Site of Action	Substrate Acting On	End Products
Salivary amylase	Salivary glands	Mouth	Polysaccharides (Starch)	Disaccharides (maltose), oligosaccharides
Pancreatic amylase	Pancreas	Small intestine	Polysaccharides (starch)	Disaccharides (maltose), monosaccharides
Oligosaccharidases	Lining of the intestine; brush border membrane	Small intestine	Disaccharides	Monosaccharides (e.g., glucose, fructose, galactose)

Protein

A large part of protein digestion takes place in the stomach. The enzyme pepsin plays an important role in the digestion of proteins by breaking down the intact protein to peptides, which are short chains of four to nine amino acids. In the duodenum, other enzymes—**trypsin**, **elastase**, and **chymotrypsin**—act on the peptides reducing them to smaller peptides. Trypsin elastase, carboxypeptidase, and chymotrypsin are produced by the pancreas and released into the duodenum where they act on the chyme. Further breakdown of peptides to single amino acids is aided by enzymes called peptidases (those that breakdown peptides). Specifically, **carboxypeptidase**, **dipeptidase**, and **aminopeptidase** play important roles in reducing the peptides to free amino acids. The amino acids are absorbed into the bloodstream through the small intestines.

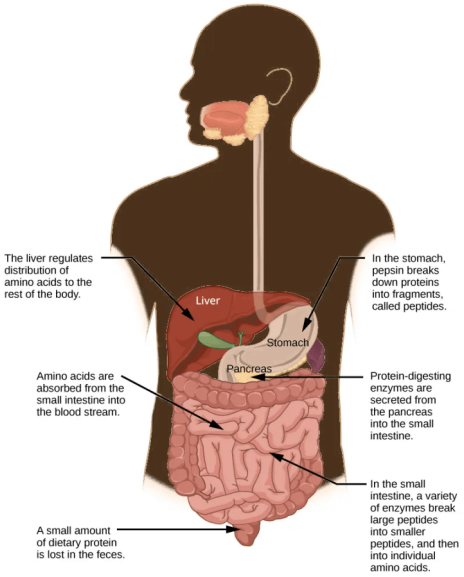


Figure 4.4.2.2: Protein digestion is a multistep process that begins in the stomach and continues through the intestines. Image from OpenStax Biology 2e / CC BY 4.0

Digestion of Protein

Enzyme	Produced By	Site of Action	Substrate Acting On	End Products
Pepsin	Stomach chief cells	Stomach	Proteins	Peptides
• Trypsin • Elastase Chymotrypsin	Pancreas	Small intestine	Proteins	Peptides
Carboxypeptidase	Pancreas	Small intestine	Peptides	Amino acids and peptides
• Aminopeptidase • Dipeptidase	Lining of intestine	Small intestine	Peptides	Amino acids

Lipids

Lipid digestion begins in the stomach with the aid of lingual lipase and gastric lipase. However, the bulk of lipid digestion occurs in the small intestine due to pancreatic lipase. When chyme enters the duodenum, the hormonal responses trigger the release of bile, which is produced in the liver and stored in the gallbladder. Bile aids in the digestion of lipids, primarily triglycerides by emulsification. Emulsification is a process in which large lipid globules are broken down into several small lipid globules. These small globules are more widely distributed in the chyme rather than forming large aggregates. Lipids are hydrophobic substances: in the presence of water, they will aggregate to form globules to minimize exposure to water. Bile contains bile salts, which are amphipathic, meaning they contain hydrophobic and hydrophilic parts. Thus, the bile salts hydrophilic side can interface with water on one side and the hydrophobic side interfaces with lipids on the other. By doing so, bile salts emulsify large lipid globules into small lipid globules.

Why is emulsification important for digestion of lipids? Pancreatic juices contain enzymes called lipases (enzymes that breakdown lipids). If the lipid in the chyme aggregates into large globules, very little surface area of the lipids is available for the lipases to act on, leaving lipid digestion incomplete. By forming an emulsion, bile salts increase the available surface area of the lipids many fold. The pancreatic lipases can then act on the lipids more efficiently and digest them. Lipases breakdown the lipids into fatty acids and glycerides. These molecules can pass through the plasma membrane of the cell and enter the epithelial cells of the intestinal lining. The bile salts surround long-chain fatty acids and monoglycerides forming tiny spheres called micelles. The micelles move into the brush border of the small intestine absorptive cells where the long-chain fatty acids and monoglycerides diffuse out of the micelles into the absorptive cells leaving the micelles behind in the chyme. The long-chain fatty acids and monoglycerides recombine in the absorptive cells to form triglycerides, which aggregate into globules and become coated with proteins. These large spheres are called **chylomicrons**. Chylomicrons contain triglycerides, cholesterol, and other lipids and have proteins on their surface. The surface is also composed of the hydrophilic phosphate "heads" of phospholipids. Together, they enable the chylomicron to move in an aqueous environment without exposing the lipids to water. Chylomicrons leave the absorptive cells via exocytosis. Chylomicrons enter the lymphatic vessels, and then enter the blood in the subclavian vein.

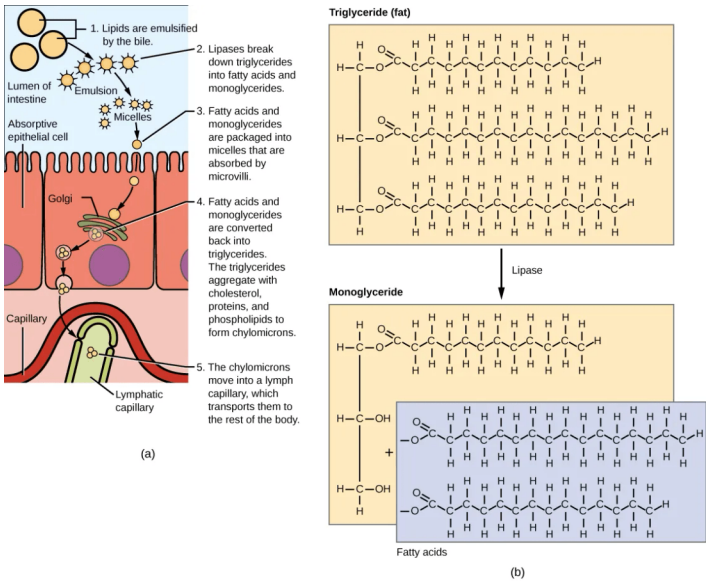


Figure 4.4.2.3: Lipids are digested and absorbed in the small intestine. Image from OpenStax Biology 2e / CC BY 4.0

Vitamins

Vitamins can be either water-soluble or lipid-soluble. Fat soluble vitamins are absorbed in the same manner as lipids. It is important to consume some amount of dietary lipid to aid the absorption of lipid-soluble vitamins. Water-soluble vitamins can be directly absorbed into the bloodstream from the intestine.

Minerals

Minerals travel through the digestive tract and into the bloodstream in various ways. For example, potassium is quickly absorbed through the wall of the small intestine and into the bloodstream. It circulates freely throughout the body, and excess is filtered out of the blood and excreted by the kidneys. Some minerals are not absorbed as easily. Vitamin B12 must bind with intrinsic factor, a protein made by cells in the stomach lining, before it can be recognized and absorbed from the intestine into the bloodstream.

Water

Water is primarily absorbed in the small intestine, especially from the first segments of the small intestine - the duodenum and jejunum. It is absorbed easily into the bloodstream. A smaller amount of water is absorbed from the large intestine.

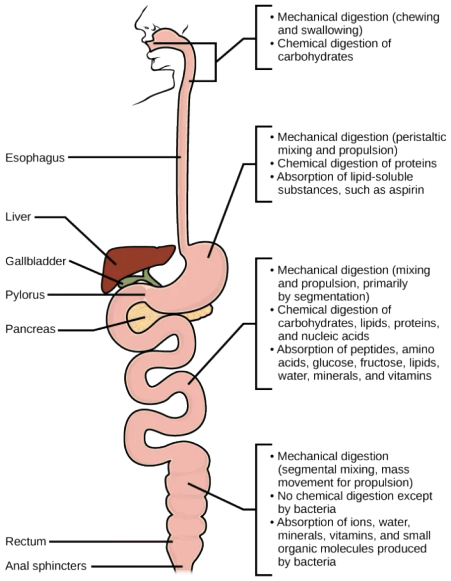


Figure 4.4.2.4: Mechanical and chemical digestion of food takes place in many steps, beginning in the mouth and ending in the rectum. Image from OpenStax Biology 2e / CC BY 4.0

Elimination

The final step in digestion is the elimination of undigested food content and waste products. The undigested food material enters the colon, where most of the remaining water is reabsorbed. Recall that the colon is also home to the microflora called “intestinal flora” that aid in the digestion process. The semi-solid waste is moved through the colon by peristaltic movements of the muscle and is stored in the rectum. As the rectum expands in response to storage of fecal matter, it triggers the neural signals required to set up the urge to eliminate. The solid waste is eliminated through the anus using peristaltic movements of the rectum.

Learning Check

Which of the following statements about digestive processes is true?

a. Amylase, maltase, and lactase in the mouth digest carbohydrates.
b. Trypsin and lipase in the stomach digest protein.
c. **Bile emulsifies lipids in the small intestine.**
d. No food is absorbed until the small intestine.

Attributions

OpenStax Biology 2e, Chapter 34.3.

Edited and expanded by Christine Bisson

Learning Check 4.4.2.1

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4.4.3: Digestive System Regulation

Learning Objectives

- Discuss the role of neural regulation in digestive processes
- Explain how hormones regulate digestion

Neural Responses to Food

The brain is the control center for the sensation of hunger and satiety. The functions of the digestive system are regulated through neural and hormonal responses. In reaction to the smell, sight, or thought of food, the first response is that of salivation. The salivary glands secrete more saliva in response to stimulation by the autonomic nervous system triggered by food in preparation for digestion. Simultaneously, the stomach begins to produce hydrochloric acid to digest the food. Recall that the peristaltic movements of the esophagus and other organs of the digestive tract are under the control of the brain. The brain prepares these muscles for movement as well. When the stomach is full, the part of the brain that detects satiety signals fullness. There are three overlapping phases of gastric control—the cephalic phase, the gastric phase, and the intestinal phase—each requires many enzymes and is under neural control as well.



Figure 4.4.3.1: Seeing a plate of food triggers the secretion of saliva in the mouth and the production of hydrochloric acid (HCL) in the stomach. Photo by Edgar Castrejon / Unsplash License

Digestive Phases

The response to food begins even before food enters the mouth. The first phase of ingestion, called the **cephalic phase**, is controlled by the neural response to the stimulus provided by food. All aspects—such as sight, sense, and smell—trigger the neural responses resulting in salivation and secretion of gastric juices. The gastric and salivary secretion in the cephalic phase can also take place due to the thought of food. Right now, if you think about a piece of chocolate or a crispy potato chip, the increase in salivation is a cephalic phase response to the thought. The central nervous system prepares the stomach to receive food.

The **gastric phase** begins once the food arrives in the stomach. It builds on the stimulation provided during the cephalic phase. Gastric acids and enzymes process the ingested materials. The gastric phase is stimulated by (1) distension of the stomach, (2) a decrease in the pH of the gastric contents, and (3) the presence of undigested material. This phase consists of local, hormonal, and neural responses. These responses stimulate secretions and powerful contractions.

The **intestinal phase** begins when chyme enters the small intestine triggering digestive secretions. This phase controls the rate of gastric emptying. In addition to gastrin emptying, when chyme enters the small intestine, it triggers other hormonal and neural events that coordinate the activities of the intestinal tract, pancreas, liver, and gallbladder.

Hormonal Responses to Food

The **endocrine system** controls the response of the various glands in the body and the release of hormones at the appropriate times.

One of the important factors under hormonal control is the stomach acid environment. During the gastric phase, the hormone **gastrin** is secreted by G cells in the stomach in response to the presence of proteins. Gastrin stimulates the release of stomach acid, or hydrochloric acid (HCl) which aids in the digestion of the proteins. However, when the stomach is emptied, the acidic environment need not be maintained and a hormone called **somatostatin** stops the release of hydrochloric acid. This is controlled by a negative feedback mechanism.

In the duodenum, digestive secretions from the liver, pancreas, and gallbladder play an important role in digesting chyme during the intestinal phase. In order to neutralize the acidic chyme, a hormone called **secretin** stimulates the pancreas to produce alkaline bicarbonate solution and deliver it to the duodenum. Secretin acts in tandem with another hormone called **cholecystokinin** (CCK). Not only does CCK stimulate the pancreas to produce the requisite pancreatic juices, it also stimulates the gallbladder to release bile into the duodenum.

Another level of hormonal control occurs in response to the composition of food. Foods high in lipids take a long time to digest. A hormone called **gastric inhibitory peptide** is secreted by the small intestine to slow down the peristaltic movements of the intestine to allow fatty foods more time to be digested and absorbed.

Understanding the hormonal control of the digestive system is an important area of ongoing research. Scientists are exploring the role of each hormone in the digestive process and developing ways to target these hormones. Advances could lead to knowledge that may help people to achieve and maintain good health.

Attributions

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4.5: Disorders of the GI Tract

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

Heartburn and Gastroesophageal Reflux

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

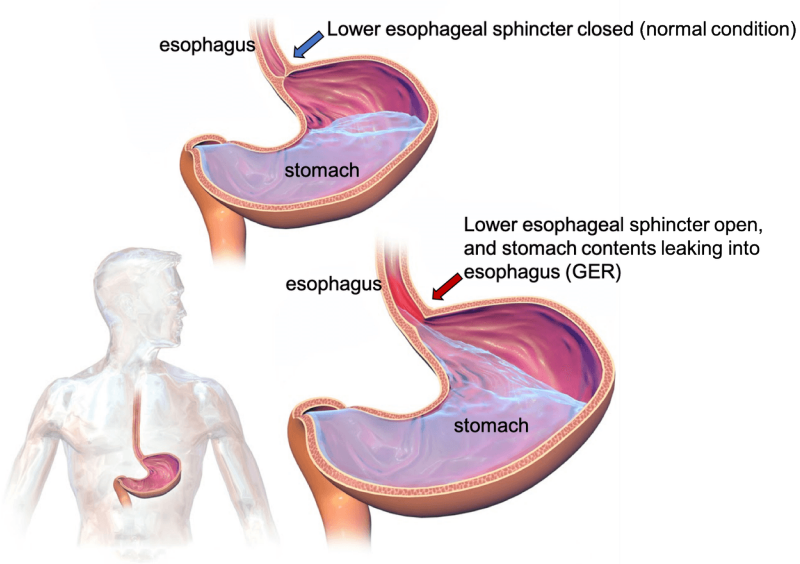


Figure 4.5.1: In gastroesophageal reflux, the acidic contents of the stomach escape backwards into the esophagus, causing pain and burning sensations in the chest and/or throat. ("GastroEsophageal Reflux Disease" by BruceBlaus is licensed under CC BY-SA 4.0)

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

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

- Avoid foods that seem to trigger symptoms. Common culprits are greasy or spicy foods, chocolate, coffee, peppermint, alcohol, and acidic foods such as tomatoes or citrus.
- Eat smaller, more frequent meals instead of large meals.
- Avoid eating 3 hours before bedtime, and stay upright for 3 hours after eating.
- Wear clothing that is loose around the abdomen.
- Raise the head of your bed by 6 to 8 inches by placing blocks under the bedposts. (Extra pillows will not help.)
- Quit smoking and avoid secondhand smoke, if needed.
- Lose weight, if needed.

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

Peptic Ulcers

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

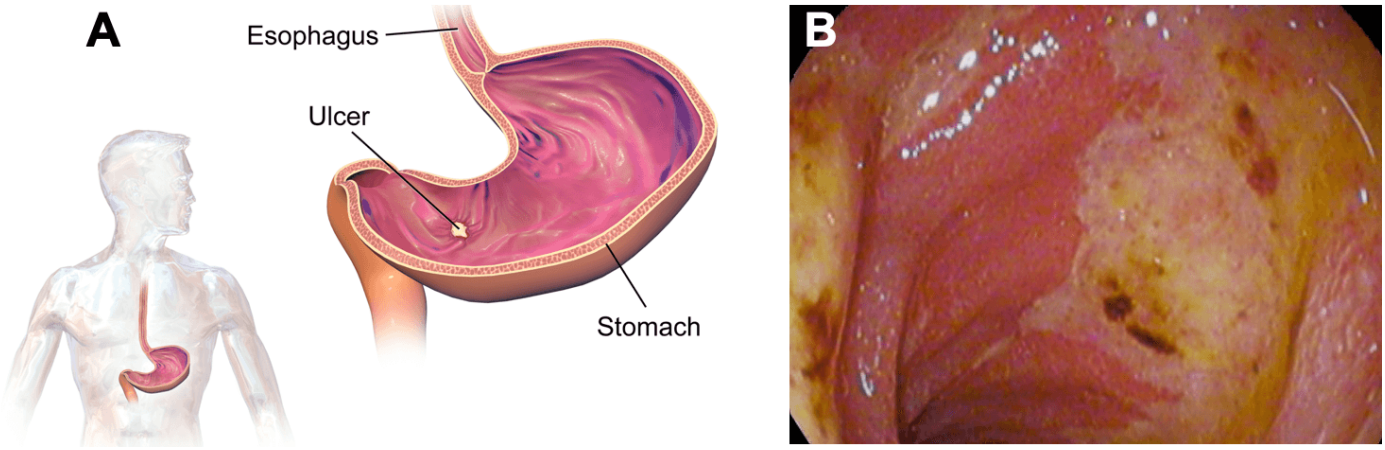


Figure 4.5.2: Peptic ulcers. (A) The location of a peptic ulcer in the stomach. (B) A photo from an endoscopy of a patient with an ulcer in the duodenum. ((a) "Gastric ulcer" by BruceBlaus is licensed under CC BY-SA 4.0 ; (b) "Duodenal ulcer A2 stage, acute duodenal mucosal lesion(ADML)" by melvil is licensed under CC BY-SA 4.0)

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

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

Diarrhea and Constipation

Both ***diarrhea*** and ***constipation*** can occur if the normal function and rhythm of the GI tract is disrupted. If waste matter moves too quickly through the large intestine, not enough water is absorbed, resulting in the loose, watery stools characteristic of diarrhea. This is most commonly caused by ingesting food or water contaminated with bacteria (e.g., *E. coli, Salmonella*), viruses (e.g., norovirus, rotavirus), or parasites (e.g., *Cryptosporidium enteritis*, *Giardia lamblia*). Dietary allergies and intolerances can also cause diarrhea, as we'll discuss on the next page. Complications of diarrhea include dehydration and malabsorption of nutrients.[4]

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

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

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

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



Figure 4.5.1: Copy and Paste Caption here. ("Abdominal pain" by derneuemann is in the Public Domain, CC0)

Irritable Bowel Syndrome (IBS)

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

Of course, since the cause of IBS isn't understood, that lack of understanding makes it difficult to treat. Some people find that eating more fiber-rich foods and increasing physical activity improve their symptoms, so these are good first steps (and good for health regardless of their effect on IBS). Others find that following a diet that is low in carbohydrates called FODMAPs helps their symptoms. FODMAPs are fermentable carbohydrates found in many foods and can usually be eaten without issue by most people. Foods that are high in FODMAPs include fruits, vegetables, legumes, dairy products, wheat, and honey, so this is a *very* restrictive

diet and should only be attempted with the guidance of a dietitian. Without careful planning, a low-FODMAP diet can be deficient in fiber, vitamins, and minerals. It is usually followed for just a few weeks, and if it helps with symptoms, foods are gradually added back to see what can be tolerated.[6,7]

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

Inflammatory Bowel Disease (IBD)

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

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

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4.6: Food Intolerances, Allergies, and Celiac Disease

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

Food Intolerances

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

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

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

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



Figure 3.17. Taking a lactase enzyme supplement allows many people with lactose intolerance to eat dairy products without suffering symptoms. ("Home-breakfast (lactaid photo)" by Ernesto Andrade is licensed under CC BY-ND 2.0)

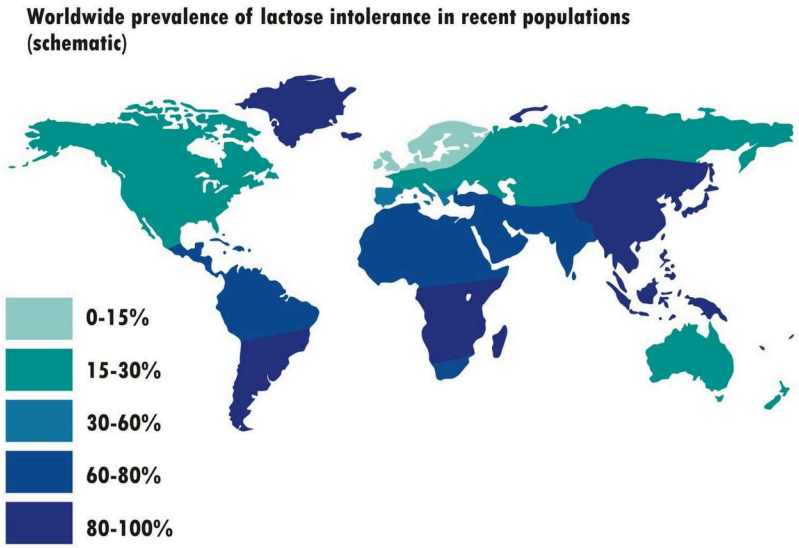


Figure 3.18. The prevalence of lactose intolerance worldwide. ("Worldwide prevalence of lactose intolerance in recent populations" by NmiPortal is licensed under CC BY-SA 3.0)

Food Allergies

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

The most common type of food allergy involves **immunoglobulin E (IgE)**, a type of antibody produced by the immune system in response to a specific substance, or ***allergen***. Symptoms of an allergic reaction usually occur immediately after consuming the food (i.e., within seconds to minutes), although reactions can sometimes be delayed by two hours or more. Because an allergic reaction is caused by the immune system, it can lead to symptoms all over the body, including skin rashes; swollen

lips, face, or throat; wheezing and difficulty breathing; nausea and vomiting; cramping; diarrhea; and rarely, a dangerous drop in blood pressure. A severe allergic reaction involving more than one organ system—a rash coupled with difficulty breathing, for example—is called ***anaphylaxis***. Anaphylaxis can be life-threatening and should be treated immediately with epinephrine, commonly administered by injection with a device such as an EpiPen, and then person should seek immediate medical attention.[1]



Figure 3.19. Common food allergens: peanuts, dairy, wheat, eggs, and shrimp. At right, an EpiPen, containing injectable epinephrine, is pictured. ("peanuts" by Tom Hermans; "cheese and bread on tray" by Alla Hetman; "fried eggs" by Gabriel Gurrola; "fried shrimp" by Jonathon Borba, all on Unsplash (license information); "Epi Pen" by Vu Nguyen is licensed under CC BY 2.0)

The most common food allergies in the U.S. are caused by proteins in peanuts, tree nuts, milk, shellfish, eggs, fish, wheat, soy and sesame.[4,5] A 2019 study reported that 19% of adults in the U.S. believe they're allergic to at least one food. After asking people about their symptoms, the researchers estimated that the true incidence of food allergies is closer to 11%, while the remaining 8% of people likely have a food intolerance.[4]

Food allergies are common in children, affecting about 8% of U.S. children, although allergies can also develop later in life.[5] It's common for young children to outgrow allergies to egg, dairy, wheat, or soy, but peanut, tree nut, and shellfish allergies are often lifelong. Recent research has found that letting babies eat common food allergens, particularly peanut products, can prevent the development of allergies, perhaps by allowing the immune system an early opportunity to learn to differentiate between food proteins and invading pathogens.[6]

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

There are some promising new therapies for treating food allergies that involve exposing a person to small amounts of the allergen to try to teach the body to tolerate it. These don't cure the allergy completely but may reduce the risk of a severe allergic reaction. The first of these therapies was approved by the U.S. Food and Drug Administration in January 2020.[7]

There are blood tests available that claim to screen for as many as 90 to 100 food allergies from one blood sample. These measure a different type of antibody called IgG, but the presence of IgG does not indicate a food allergy. Therefore, these tests are not recommended by allergy experts, because they may cause a person to unnecessarily fear and avoid a long list of foods to which they are not allergic.[8]

Celiac Disease

Celiac disease is an autoimmune disorder affecting between 0.5 and 1.0% of people in the U.S., or one in every 100 to 200 people.[9] In ***autoimmune diseases***, the immune system produces antibodies that attack and damage the body's own tissues. In the case of celiac disease, the body has an abnormal immune reaction to ***gluten*** (a group of proteins found in wheat, rye, and and barley), causing antibodies to attack the cells lining the small intestine. This results in damage to the villi, decreasing the surface area for nutrient absorption. There is no cure for celiac disease, but it's very effectively treated by eliminating gluten from the diet.[10]

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

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

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

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



Figure 3.20. Celiac disease is caused by an autoimmune response to gluten, found in wheat, rye, and barley. At right is a section of the small intestine from a biopsy, visualized under a microscope, from a celiac patient. The villi, which would normally be finger-like projections, are blunted and flattened by damage caused by the disease. ("bread" by Wesual Click on Unsplash (license information); "coeliac path" by Samir is licensed under CC BY-SA 3.0)

Celiac disease is different from a wheat allergy in both cause and symptoms. Because celiac disease is an autoimmune condition, the cells of the small intestine come under attack, and damage causes chronic symptoms. A wheat allergy, on the other hand, is

caused by antibodies attacking an allergen in the wheat itself, and the symptoms are usually immediate and acute.

Sometimes, people test negative for celiac disease but still believe that consuming gluten is causing symptoms, usually gastrointestinal in nature. They may eliminate gluten from their diet and find that they feel better. This is often called ***non-celiac gluten sensitivity (NCGS)***. It's not clear what causes NCGS or why a gluten-free diet is helpful. In some cases, it may be a placebo effect. In others, it seems that it's not gluten causing the problem but other dietary components, such as FODMAPs, that happen to also be low in a gluten-free diet. And in some cases, gluten does seem to cause symptoms in people without celiac disease, although researchers don't understand why.[11,12]

Except in the case of celiac disease, wheat allergy, or confirmed NCGS, gluten-free foods or a gluten-free diet are not inherently more healthful. In fact, packaged gluten-free foods are often more highly processed, with more added sugar, salt, and fat, compared to foods containing wheat. A gluten-free diet can also be lower in fiber, so those following the diet should be sure to include naturally gluten-free whole grains, legumes, nuts, fruits, and vegetables to provide adequate fiber.[13]

Attributions

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4.7: The Gut Microbiome

The Gut Microbiome

The gut microbiome — the densely populated community of bacteria, archaea, viruses, and fungi residing in our intestines — is now understood to play a foundational role in human health, especially through its intimate crosstalk with the immune system. It has been shown to affect numerous other regions of the body and serves a role in many types of diseases throughout it. This is because many of the microbial products are absorbed in the alimentary canal and distributed throughout the body via the cardiovascular system.

Over the past decade, researchers have illuminated how early-life trajectories of gut microbial colonization and metabolism shape immune development and susceptibility to allergic and inflammatory disease. For example, perturbations in microbial-derived metabolites are linked to skewed T-cell programming in infancy (Fujimura et al., 2016). Additionally, we have advanced our mechanistic understanding of how diet modulates microbial community structure, function, and resilience (Wastyk et al., 2021), and now understand that dietary fiber or its loss can influence not only which taxa persist but also how microbial genes are expressed (Goldman, 2016). New research delves into how fermented foods are not just "live microbes" but also sources of bioactive metabolites that can influence host-microbe and microbe-microbe interactions. This work tracks the metabolite composition of fermented foods and how those compounds might engage with the gut microbiome and human biology (Caffrey et al., 2024).

The immune-microbiome interface is nowhere more critical than in the gut: it is sometimes claimed that approximately 70% of the immune system resides in the gut-associated lymphoid tissues (Cohen, 2021), and that the gut is the most densely populated microbial habitat in humans — anywhere from 70–90% of all the microorganisms in the body are thought to be found in the large intestine. However, a careful review of the literature indicates that these are rough heuristics rather than rigorously established constants. In any case, the microbiome associated with the human gastrointestinal tract, could arguably be the most important component of the collective human microbiome.

When it comes to the gut microbiome and its relationship to nutrition, we presently have more questions than answers. Despite growing interest and advances in technology, the gut remains an incredibly complex and difficult environment to study. Much of our current understanding relies on fecal samples, which offer a readily available and non-invasive means of accessing microbial communities. However, these samples represent only a portion of the gut's ecosystem, often missing nuances that occur closer to the intestinal lining. Recent efforts, such as sampling the mucosal-luminal interface (Yan et al., 2020), aim to provide a more detailed and localized picture of microbial life. From these samples, researchers can extract DNA and other molecular markers to begin unraveling the composition and potential functions of the gut microbiome — though much remains to be discovered.

The video below provides an overview of some of the ways the food we eat is thought to affect the gut, serving as a dynamic companion to the information presented in the text that follows.

Interactive Content

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Video 4.7.1: How the food you eat affects your gut by Shilpa Revella, Ted-Ed (March 2017). 4:55 minutes.

Composition

The gut microbiome is quite versatile and its composition can vary widely among individuals with different ethnicities, across geographic locations, and with age (Yatsunenko et al., 2012, Gaulke and Sharpton, 2018). The host's genetics do play a role in the composition of the gut microbiome, as certain members are heritable, while other's abundances are the causal result of congenital diseases (Xu et al., 2020). Though diet, which is closely related to the aforementioned variables, may be the single strongest influencing factor when it comes to structuring this digestive community and alterations are reflected in both short-term and long-term dietary interventions (David et al., 2014, Xu and Knight, 2015). Indeed, the type of diet, such as a high-fat diet, will have a direct impact on the gut microbiome. More specifically, the unique macromolecules within the gut can modify microbial abundance and predicted functions. For example, a certain oil in the diet could result in higher microbial richness, however, this diversity may not alone be a predictor of better health outcomes (Abulizi et al., 2019). Dietary vitamin content and even receptors required for processing them are in part modulated by the microbiome. For example, vitamin D deficiency and downregulation of its affiliated receptor is associated with pathogenesis of various diseases and their restoration promotes healthy host-microbe homeostasis (Jin et al., 2015). It is also interesting to note that diet usually changes throughout the year as certain food items become available or absent depending on the season. An increased gut prevalence of Bacteroidetes, which can digest complex plant carbohydrates, could be explained by a diet consisting heavily of produce during a harvest season (Davenport et al., 2014). The composition and diversity of the gut microbiome can even be linked to personality traits. Those individuals with larger social networks have a more diverse gut microbiome, and those affected by stress and anxiety show an altered composition with reduced diversity (Johnson, 2020). The connection between the gut microbiome and mental states and behaviors will be discussed more in the section "Mental Health".

Video Quiz

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Dysbiosis and Disease

The gastrointestinal mucosal immune system modulates and responds to the gut microbiome, where the resident members aid in its development and transient pathogens cause dysfunction, leading to various diseases (Shi et al., 2017). Inflammatory diseases such as systemic lupus erythematosus, rheumatoid arthritis, IBD, and ankylosing spondylitis are implicated in the impaired interaction between the intestinal microbiota and mucosal immune system (Arbuckle et al., 2003, Mikuls et al., 2012, Costello et al., 2015). Microbial dysbiosis within these cases are marked by changes in composition and diversity of specific groups of organisms (Shi et al., 2017). So, the gut microbiome can not only serve as an indicator for such diseases, but may also eventually become a target for treatment, with maintaining proper homeostasis a major goal.

Gut microbiome dysbiosis, whether it causes a particular disease or manifests as a result of it, is quickly becoming the focus of many gastrointestinal illnesses. Specific members of the gut microbiome (e.g. bacteriome, mycobiome, virome) can even vary and be affected differently depending on the disease and its severity. For example, while much of the focus is usually on bacteria in the gut, it is important to not discount the contributions of other microorganisms like bacteriophages and fungi. The gut phageome can vary in diversity, complexion, and in so has been shown to contribute to diseases like IBD, malnutrition, and AIDS (Norman et al., 2015, Reyes et al., 2015, Monaco et al., 2016, Shkoporov and Hill, 2019). Similarly, the gut mycobiome has shown to have roles in IBD, colorectal cancer, and even neurological diseases (Forbes et al., 2019, Gu et al., 2019, Qin et al., 2021). Though, it is likely the complex interactions between all members of the gut microbiome with the host undoubtedly play a role in various degrees for the progression of gastrointestinal and other diseases.

Those with Inflammatory Bowel Disease (IBD) experience substantial fluctuations in the gut microbiome, which is implicated due to signs and symptoms of the disease state, diet, as well as increased medication during flare ups (Walters et al., 2014, Halfvarson et al., 2017). IBD is a blanket term for two disorders, ulcerative colitis and Crohn's disease, which are characterized by chronic

inflammation of the gastrointestinal tract and commonly results in frequent diarrhea, abdominal pain, bloody stool, weight loss, and fatigue. It is likely that the gut microbiome plays both a role in the development of these conditions and is affected by the induced changes. The gut virome component responds to disease-induced environmental change of IBD patients by shifting from virulent to temperate bacteriophage core, which subsequently affects the bacteriome and dysbiosis condition (Clooney et al., 2019). A familial study of patients with Crohn's disease showed an increase in the number of pathogenic bacteria, and a decrease in beneficial bacteria. In particular, three potentially pathogenic biofilm-forming species from both the bacteriome (*Serratia marcescens* and *Escherichia coli*) and mycobiome (*Candida tropicalis*) interact with each other and impact the host immune system by increasing levels of proinflammatory cytokines and mucolytic enzymes which cause oxidative and tissue damage (Hoarau et al., 2016).

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Diabetes mellitus is another disease in which its progression is partially in response to gut microbiome dysbiosis. While there are other factors that play into diabetes such as culture, genetics, age, lifestyle, etc., this can be interlinked with an individual's microbiome. Studies over both type 1 and type 2 diabetes have shown that a change in the gastrointestinal microbial ecology is associated with diabetic subjects as compared with their healthy counterparts (Giongo et al., 2010, Larsen et al., 2010, Musso et al., 2011, Sohail et al., 2017). Type 1 diabetes stems from destruction of pancreatic beta cells, which results in decreased insulin production and elevated blood glucose levels. The gut microbiome may contribute to the disease by dysbiosis-associated immune regulation causing destruction of the beta cells and/or gut leakiness, endotoxemia, and chronic low-grade inflammation associated with certain enteric microbes (Cani et al., 2007, Lee et al., 2011, McDermott and Huffnagle, 2014, Sohail et al., 2017). Type 2 diabetes is characterized by the body's improper regulation and secretion of insulin and is associated by hyperglycemia. Physiological changes in the GI tract could be induced by dysbiosis in the gut microbiome leading to gut permeability and insulin resistance (Everard and Cani, 2013). In general, the gut microbiota composition is less in terms of diversity and richness for those with type 2 diabetes, though an increase in abundance of certain groups like *Bifidobacterium* could improve conditions associated with pathogenesis (Cani et al., 2007, Sohail et al., 2017). It seems that an alteration of the microbial gut profile has considerable effects on host metabolism, gastrointestinal physiology, gut fermentation capabilities, and immunity which can have many other downstream implications (Boulange et al., 2016).

Obesity is commonly associated with type 2 diabetes as well as other comorbidities that are linked to gut microbiome dysbiosis. As mentioned earlier, diet strongly affects the composition and function of the gut microbial community and subsequently impacts the host's metabolic capabilities. In fact, a high-fat/calorie or improper diet that results in dysbiosis is evident earlier than the signs of the host's metabolic abnormalities, and so gut microbiome dysbiosis may be the principle ingredient responsible for the progression of obesity and type 2 diabetes (Nagpal et al., 2018). A high-sugar diet seems to promote an abundance of *Mollicutes*, a class within Firmicutes, which in turn suppresses Bacteroidetes (Turnbaugh et al., 2008), and this higher ratio of Firmicutes/Bacteroidetes has been proposed as a biomarker and hallmark indicator for obesity (de Bandt et al., 2011, Zou et al., 2020). However, it is important to consider other factors such as physical activity and medication that could cause a variation in diversity of the gut microbiome, as this ratio does not always definitively denote obesity (Magne et al., 2020). Though, there are similarities between many of the microbiome-linked contributing factors of pathogenesis progression for diet-induced diseases. For example, a high-fat diet induces increased gut permeability that allows exogenously produced bacterial compounds (e.g. lipopolysaccharides) to diffuse through the intestinal barrier, which then can interact with immune cells and lead to inflammation (Cani et al., 2007, Nagpal and Yadav, 2017). However, diet isn't the sole factor that can promote gut leakiness, and it seems that obesity in general causes an altered gastrointestinal state (Nagpal et al., 2018).

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Chemotherapeutic Intervention and C. diff

Medication and antimicrobial drugs can also have drastic effects on the gut microbiome that invoke risk of secondary infections, allergies, and other diseases like obesity (Becattini et al., 2016). Though many of these prescribed treatments are necessary to combat infectious diseases, the aftermath may have more serious consequences. Not only does antimicrobial therapy disrupt the resident microbiome, but misuse, suboptimal dosing, and patient noncompliance can create conditions conducive to fostering antimicrobial resistance through selective pressure.

Clostridioides difficile (commonly called C. diff) infections are directly associated with antibiotic-induced dysbiosis in the gastrointestinal tract. *C. difficile* is part of the normal microbiota, however, as an opportunistic pathogen it can invade or colonize empty niches brought about by dysbiosis and cause potentially fatal episodes of pseudomembranous colitis, which is associated with abdominal cramping, pain, sepsis, and bouts of diarrhea (Kho and Lal, 2018). Infection and transmission of this organism has been well known for its prevalence in hospital settings, primarily affecting the elderly and immunocompromised, however, community-associated infections have recently increased in what was once considered low-risk populations (Rouphael et al., 2008, Baker et al., 2010, Hensgens et al., 2012, Benson et al., 2015, Johanesen et al., 2015). It is also alarming that this organism has resistance mechanisms to many commonly prescribed antimicrobials, including β-lactams, aminoglycosides, lincomycin, tetracyclines, and erythromycin (George et al., 1978), and more recently 'hypervirulent' strains have developed resistance to fluoroquinolones (He et al., 2013, Johanesen et al., 2015). *C. difficile* infections have an enrichment of fungi that associate with the bacteriome and perhaps antifungal therapy could help improve treatment success if administered in conjunction with specific antibacterial drugs (Stewart et al., 2019). Though, these infections can have lingering impacts on the gut microbiome, as further antimicrobial therapy that is usually required can perpetuate the situation. The inflammation as a result of the disease induces the production of antimicrobial peptides by epithelial cells and neutrophils which inhibit the growth of the natural resident commensal microbes (Leber et al., 2015).

While many events of gut dysbiosis are directly linked to the chemotherapeutic effects on microbes since they are prescribed to target microbes responsible for the infection, some medications which are meant to address other diseases, like antidepressants for mental health, have undesired effects on the microbiome (Maier and Typas, 2017). In the cases of multi-drug combinations (e.g. non-steroidal anti-inflammatory drugs (NSAIDs), antidepressants, laxatives, proton-pump inhibitors (PPIs), etc.), it is not the number of drugs that affect gut microbiome diversity, but rather the types of drugs (Rogers and Aronoff, 2016). Though these scenarios become complicated as it is difficult to ascertain whether the alterations observed on the microbiome are from the drug's mechanism of action, a downstream side effect, or originate from the condition that is being treated, and it is likely a complex combination of all factors for each disease and medication (Rogers and Aronoff, 2016, Maier and Typas, 2017, Jackson et al., 2018).

Fecal Microbiota Transplant

Although pharmaceutical drugs are of dire importance to treat various diseases, whether they are infectious in nature or not, other avenues must be pursued for those that may benefit from restoration of the gut microbiome. Probiotics and fecal microbiota transplant (FMT) can serve as viable options for the prevention and treatment of gut microbiome dysbiosis. Probiotics are considered foodstuffs with microorganisms, usually bacteria (many being lactic acid bacteria) and yeast, and their byproducts that have a beneficial effect on human health when introduced into the body. Many probiotics are commercially available to consumers in the forms of products like yogurt, kefir, buttermilk, sauerkraut, pickles, premade vitamin supplements and many others (more information about probiotics and fermented foods can be found in the section "Food and Fermentation: Your Microbiome is What you Eat"). Specifically, probiotics can be used for the treatment and prevention of many of the aforementioned gut microbiome dysbiosis-associated diseases, especially those induced by antibiotics (Kim et al., 2019). The beneficial microbes outcompete pathogens for resources or prevent them from establishing a niche in which to grow (Ouwehand et al., 1999).

In more extreme cases of gut microbiome dysfunction and disease, like those from *C. difficile* infection (CDI) in which antibiotics are ineffective and can potentially exacerbate the problem, other measures must be taken. Fecal microbiota transplant therapy takes a stool sample containing the gut microbiome from a healthy donor and relocates it into the infected patient's colon. The introduced microbiota then helps move the gut microbiome towards homeostasis by restoring the structure of beneficial microbes and metabolites (Fujimoto et al., 2021). This procedure is usually reserved for those patients with recurrent CDI and has shown to be highly successful and is considered safer and more effective than prolonged antibiotic usage (Mattila et al., 2012, Cammarota et al., 2015), though is also being investigated for first-line treatment of CDI (Camacho-Ortiz et al., 2017). FMT has gained traction for its success and is being further considered as a therapeutic option in other treatment protocols, such as those for cancer patients undergoing cancer immunotherapy to help improve response or manage toxicity (McQuade et al., 2020), and individuals undergoing allogenic hematopoietic stem cell transplant for hematological disorders that experience graft-versus-host disease complications from it (Zhang et al., 2021). However, precautions must be taken for FMT, as the donor's sample could potentially harbor other pathogenic microbes, like multi-drug resistant *Escherichia coli*, that can result in pathogenesis, further complications, and even death for the recipient (DeFilipp et al., 2019, Martinez-Gili et al., 2020). More comprehensive research and FMT trials must be performed in order to optimize this procedure to better match donors with recipients and to further understand the exact mechanisms of microbiome rehabilitation.

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Conclusion

Gut microbiome intervention may be the key to future treatments of diseases associated with dysbiosis like IBD, diabetes, obesity, colorectal cancer, and others, and offers a viable alternative to many traditional pharmaceutical interventions. However, the gut microbiome is plastic and continually changes with its host's environment and lifestyle, so stabilization is constant work. Additionally, creating an ideal 'cocktail' of microbes that will maintain homeostasis when implemented can be challenge. While there are general members of the gut microbiome that exist at a constant level and show some correlation to normal health, there may not be a true 'standard' gut microbiome due to the vast differences between people across the world. So, this type of therapy may require a more unique and individualized approach that depends on the disease and characteristics of both the host and their microbiome.

Check Your Understanding

- What factors influence the composition of the gut microbiome?
- How is gut microbiome dysbiosis brought about?

- What diseases are associated with gut microbiome dysbiosis? Are features of pathogenesis always a cause or effect of these events? Explain.
- Explain the treatment options that are available for gut microbiome dysbiosis.

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4.8: Research Highlight - The Gut-Brain Connection

Learning Objectives

Review and critically evaluate a scholarly, peer-reviewed, primary research publication.

*Note: Each chapter of Introduction to Nutrition Science includes a Research Highlight like this one. The purpose of each of these is to extend your knowledge of the chapter content to relevant research. A primary research publication is one in which the results of the author's research contribute new knowledge to the field of study.

Introduction

In this chapter, you have been introduced to some of the mechanisms for providing dietary guidance to North Americans. This guidance is based on research demonstrating the biological need for each nutrient currently identified. In the following publication, the authors discuss the effect of the food we eat on the health of the bacteria that live in our gastrointestinal systems. As you read the publication linked below, consider the following questions:

1. What are your initial thoughts regarding the aim of this publication?
2. What is the question that the author is trying to answer with this publication?
3. What methods did the author use to determine an answer to the question?
4. What sorts of results did the author obtain, and how were those results analyzed?
5. What types of references does the author use to support the publication?
6. Do you agree with the conclusions to which the author came regarding an answer to the question?

Primary Publication

Fields, F. J., Lejzerowicz, F., Schroeder, D., Ngoi, S. M., Tran, M., McDonald, D., Jiang, L., Chang, J. T., Knight, R., Mayfield, S. (2020). Effects of the microalgae *Chlamydomonas* on gastrointestinal health. *Journal of Functional Foods*, 65, 103738. DOI: https://doi.org/10.1016/j.jff.2019.103738

Further evaluation

To evaluate this publication further, it might help to know a little more about some work being performed by Rob Knight (one of the senior authors on the primary publication linked above) at the University of California, San Diego. In this TED talk he presented several years ago, he discusses the relationship humans have with the bacteria living in our guts, and a novel type of research study they are using to gather more information about the relationship of those bacteria with human health.

Video 4.8.1: Rob Knight: How our microbes make us who we are

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CHAPTER 5: CARBOHYDRATES

Learning Objectives

After completing this unit, you should be able to:

1. Classify the different types of carbohydrates, identify their food sources, and discuss how these carbohydrates are digested and absorbed in the body.
2. Define the guidelines for total carbohydrate, fiber, and added sugar intake.
3. Explain how glucose is regulated and utilized in the body and describe how the body adapts to a low carbohydrate intake.
4. List the causes, complications, and treatment for different types of diabetes.
5. Be able to describe the health benefits, types of, and food sources of dietary fiber.
6. Differentiate between whole and refined grains in foods by examining food labels.
7. Distinguish between added and natural-occurring sugars in foods, and discuss health implications of too much added sugar.
8. Identify sugar substitutes in foods, and describe potential benefits and drawbacks of sugar substitutes.

5.1: Introduction to Carbohydrates

5.2: Types of Carbohydrates

5.3: Carbohydrate Food Sources and Guidelines for Intake

5.4: Digestion and Absorption of Carbohydrates

5.5: Glucose Regulation and Utilization in the Body

5.6: Fiber - Types, Food Sources, Health Benefits, and Whole vs. Refined Grains

5.7: Sugar — Food Sources, Health Implications, Intakes, and Label-Reading to Identify Sugar

5.8: Sugar Substitutes

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5.1: Introduction to Carbohydrates

If someone says to you, “I love carbohydrates, and I eat them all day long!” what would you assume they’re eating?

Do you picture this?



Figure 4.1. ”Potato chips” by Kate Ter Haar is licensed under CC BY 2.0; “M&Ms” by Wade Brooks is licensed under CC BY-NC 2.0; “Pecan pastry” by Artizone is licensed under CC BY-NC-ND 2.0

And this?



Figure 4.2. Examples of carbohydrate-rich snack foods. “Bread” by David Stewart is licensed under CC BY 2.0; “Pasta” by Yasumari SASAKI is licensed under CC BY 2.0; “Rice” by Francesca Nocella is licensed under CC BY-SA 2.0.

When we ask this question in class, most students describe foods like the ones above. However, carbohydrates are found not just in grains, or in sweets and processed foods, but in **every** food group.

In fact, carbohydrates are the most abundant nutrient (except water) in the diets of most humans around the world. Since the dawn of agriculture, human cultures have relied on staple grains, such as corn, rice, and wheat, as the foundation of their diets, and these foods are rich in carbohydrates. But fruits and vegetables, dairy products, legumes, and nuts also have naturally-occurring carbohydrates. And of course, carbohydrates are a key ingredient in desserts, sugar-sweetened beverages like sodas, and many of the packaged snack foods that are readily available and—let’s face it—can be hard to stop eating.

In other words, if someone says they eat a high carbohydrate diet, that could mean many different things. They very well could be talking about a balanced diet focused on whole foods, like this:



Figure 4.3. Examples of whole foods containing carbohydrates, including fresh fruit, legumes and grains, and cheese. Examples of grain-based foods. “Assorted Fruit Bowl” by Allen Gottfried is licensed under CC BY-SA 2.0; “Schalen mit verschiedenen Getreidesorten wie Reis, Hirse, Linsen, Erbsen und Buchweizen” by Marco Verch is licensed under CC BY 2.0; “Cheese” by Finite Focus is licensed under CC BY-NC 2.0.

The diet industry likes to sell us simple messages about “good” and “bad” foods, and these days, we tend to hear that carbohydrates are in the “bad” group. But given that carbohydrates are in so many different types of foods, that’s obviously an oversimplified message—and it’s not fair to all of the awesome sources of carbohydrates in the world of food. Not all carbohydrate-rich foods are the same. In this unit, you’ll learn to appreciate the nutrient-dense carbohydrate foods, identify which don’t offer as valuable a nutritional package, and understand how a balanced diet can include all of them.

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5.2: Types of Carbohydrates

On this page, we'll get acquainted with the chemical structure of different types of carbohydrates and learn where we find them in foods.

First, all carbohydrates are made up of the same chemical elements:

- carbon (that's the "carbo-" part)
- hydrogen and oxygen, in about a two-to-one proportion, just like in H_2O (that's the "-hydrate" part)

For this reason, you may see carbohydrates abbreviated as "CHO" in our class.

Carbohydrates can be divided into two main types: simple and complex. Simple carbohydrates are made up of just one or two sugar units, whereas complex carbohydrates are made up of many sugar units. We'll look at each of these in turn. This figure gives you an overview of the types of carbohydrates that we'll cover.

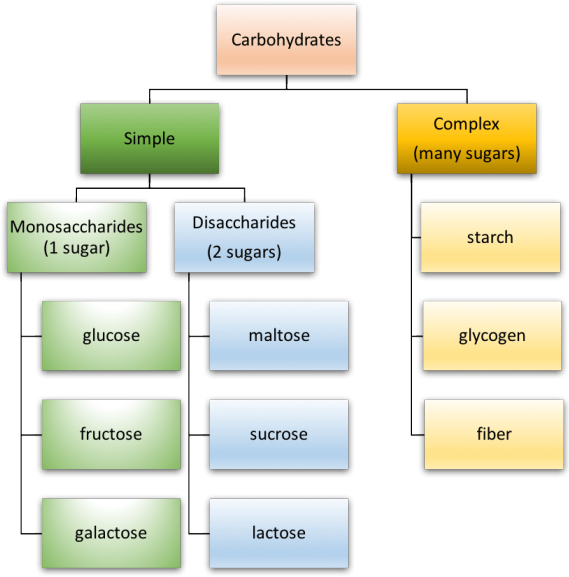


Figure 5.2.1: Carbohydrates can be divided into two main types: simple (including monosaccharides and disaccharides) and complex.

Simple carbohydrates

Simple carbohydrates are sometimes called "sugars" or "simple sugars." There are 2 types of simple carbohydrates: **monosaccharides** and **disaccharides**.

Monosaccharides contain just one sugar unit, so they're the smallest of the carbohydrates. (The prefix "mono-" means "one.") The small size of monosaccharides gives them a special role in digestion and metabolism. Food carbohydrates have to be broken down to monosaccharides before they can be absorbed in the gastrointestinal tract, and they also circulate in blood in monosaccharide form.

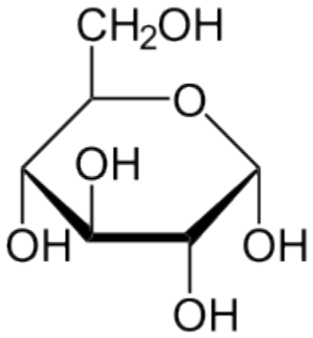
There are 3 monosaccharides:

1. **Glucose**
2. **Fructose**
3. **Galactose**

Note that all three have the same chemical formula ($C_6H_{12}O_6$); the atoms are just arranged a bit differently.

Glucose

Here's the chemical structure of ***glucose***:



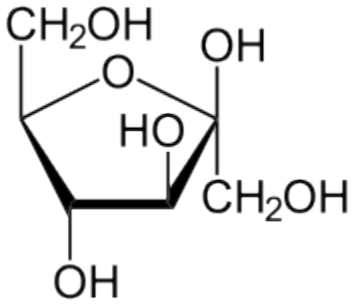
You're already familiar with glucose, because it's the main product of photosynthesis. Plants make glucose as a way of storing the sun's energy in a form that it can use for growth and reproduction.

In humans, **glucose is one of the most important nutrients for fueling the body. It's especially important for the brain and nervous system, which aren't very good at using other fuel sources.** Muscles, on the other hand, can use fat as an energy source. (In practice, your muscles are usually using some combination of fat and glucose for energy, which we'll learn more about later.)

Food sources of glucose: Glucose is found in fruits and vegetables, as well as honey, corn syrup, and high fructose corn syrup. (All plants make glucose, but much of the glucose is used to make starch, fiber, and other nutrients. The foods listed here have glucose in its monosaccharide form.)

Fructose

Here's the chemical structure of ***fructose***:



Fructose is special because it is the sweetest carbohydrate. **Plants make a lot of fructose as a way of attracting insects and animals, which help plants to reproduce.** For example, plants make nectar, which is high in fructose and very sweet, to attract insects that will pollinate it. Plants also put fructose into fruit to make it tastier. Animals eat the fruit, wander away, and later poop out the seeds from the fruit, thereby sowing the seeds of the next generation. Animal gets a meal, and the plant gets to reproduce: win-win!

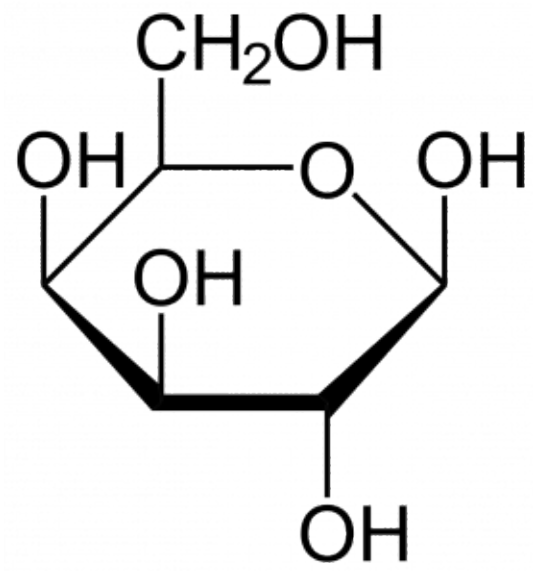


Figure 5.2.2: Fructose in nature: A bee collects sweet nectar from a flower, in the process spreading pollen from flower to flower and helping plants to reproduce. Bees use nectar to make honey, which humans harvest for use as a sweetener. (Honey contains a mix of sucrose, fructose, and glucose). A kiwi is sweetened in part by fructose. Animals enjoy the sweet fruit and then later poop out the seeds, sowing them for a new generation of kiwi trees.

Food sources of fructose: Fruits, vegetables, honey, high fructose corn syrup

Galactose

Here is the chemical structure of ***galactose***:



Food sources of galactose: Galactose is found in milk (and dairy products made from milk), but it's almost always linked to glucose to form a disaccharide (more on that in a minute). We rarely find it in our food supply in monosaccharide form.

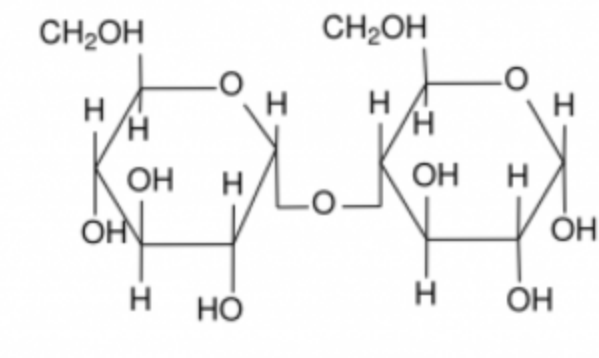
The second type of simple carbohydrates is ***disaccharides***. They contain two sugar units bonded together.

There are 3 disaccharides:

1. **Maltose (glucose + glucose)**
2. **Sucrose (glucose + fructose)**
3. **Lactose (glucose + galactose)**

Maltose

Here is the chemical structure of ***maltose***:



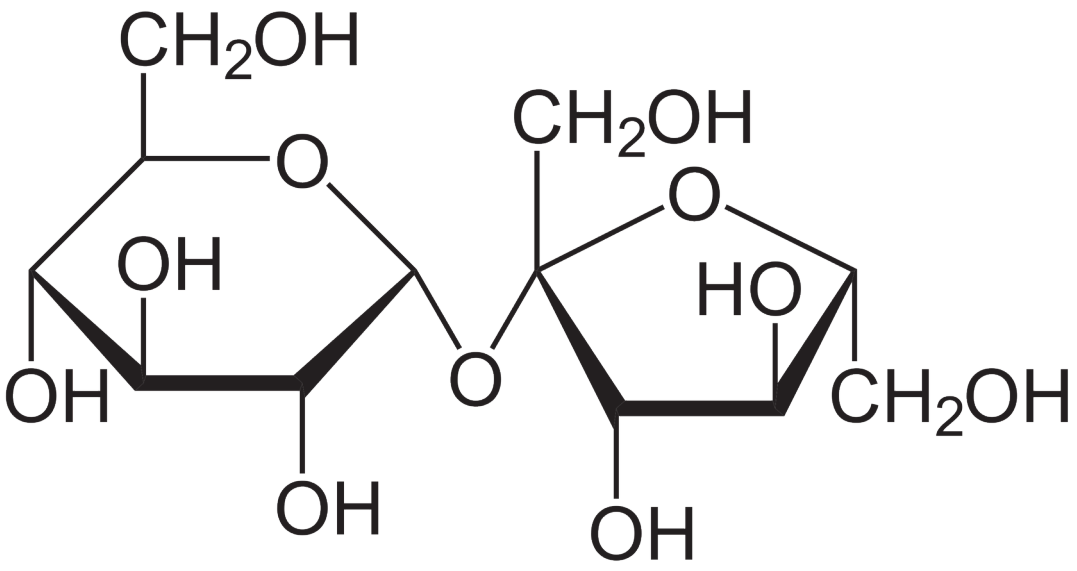
Maltose is made of **two glucose molecules** bonded together. **It doesn't occur naturally in any appreciable amount in foods, with one exception: sprouted grains**. Grains contain a lot of starch, which is made of long chains of glucose (more on this in a minute), and when the seed of a grain starts to sprout, it begins to break down that starch, creating maltose. If bread is made from those sprouted grains, that bread will have some maltose. Sprouted grain bread is usually a little heavier and sweeter than bread made from regular flour.

Maltose also plays a role in the production of beer and liquor, because this process involves the fermentation of grains or other carbohydrate sources. Maltose is formed during the breakdown of those carbohydrates, but there is very little remaining once the fermentation process is complete.

You can taste the sweetness of maltose if you hold a starchy food in your mouth for a minute or so. Try this with a simple food like a soda cracker. Starch is not sweet, but as the starch in the cracker begins to break down with the action of salivary amylase, maltose will form, and you'll taste the sweetness!

Sucrose

Here is the chemical structure of ***sucrose***:



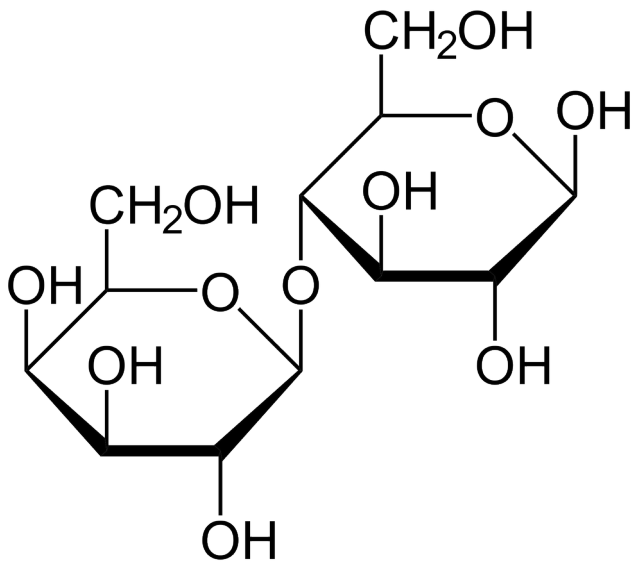
Sucrose is made of a **glucose molecule** bonded to a **fructose molecule**. It's made by plants for the same reason as fructose — to attract animals to eat it and thereby spread the seeds.

Sucrose is naturally-occurring in fruits and vegetables. (Most fruits and vegetables contain a mixture of glucose, fructose, and sucrose.) But humans have also figured out how to concentrate the sucrose in plants (usually sugar cane or sugar beets) to make **refined table sugar.** We also find sucrose in **maple syrup and honey.**

The sucrose found in a sweet potato is chemically identical to the sucrose found in table sugar. Likewise, the fructose found in a fig is chemically identical to the fructose found in high fructose corn syrup. As we'll discuss more later, what's different is the package the sugars come in. When you eat a sweet potato or a fig, you also get lots of fiber, vitamins, and minerals in that package, whereas sugar and high fructose corn syrup only provide sugar, nothing else. It's not a bad thing to eat sugar. After all, it's a vital fuel for our brain and nervous system. But paying attention to the package it comes in can help us make good overall choices for health.

Lactose

Here is the chemical structure of ***lactose***:



Lactose is made of a **glucose molecule** bonded to a **galactose molecule**. It is sometimes called "milk sugar" as it is found in **dairy products like milk, yogurt, and cheese**. These are the only animal foods that have significant amounts of carbohydrate. Most of our carbohydrates come from plant foods.

Complex carbohydrates

Complex carbohydrates are also called polysaccharides, because they contain many sugars. (The prefix "poly-" means "many.") There are 3 main polysaccharides:

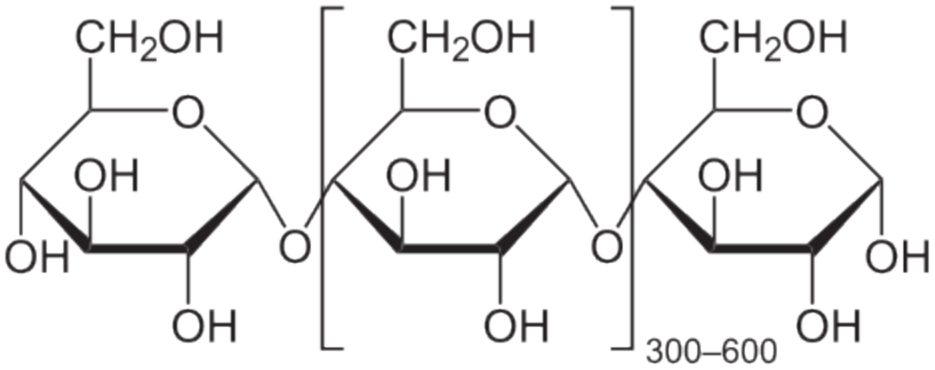
1. Starch
2. Glycogen
3. Fiber

All three of these polysaccharides are made up of many glucose molecules bonded together, but they differ in their structure and the type of bonds.

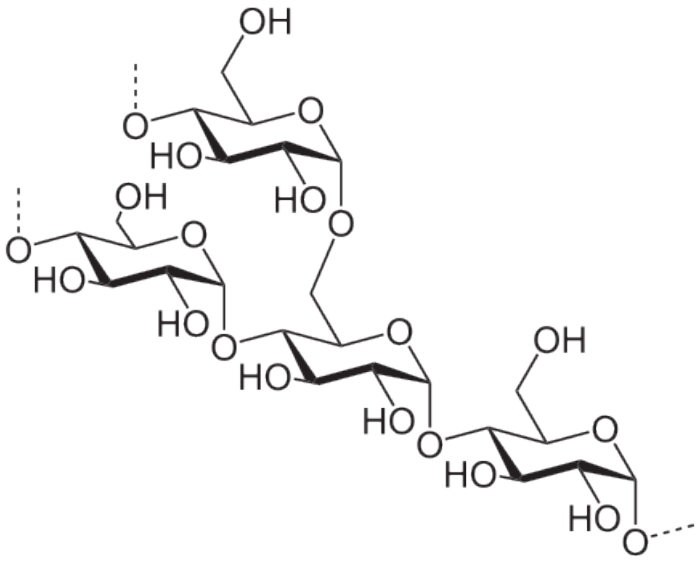
Starch

Starch is made up of long chains of glucose. If these chains are straight, they're called amylose; if they're branched, they're called amylopectin.

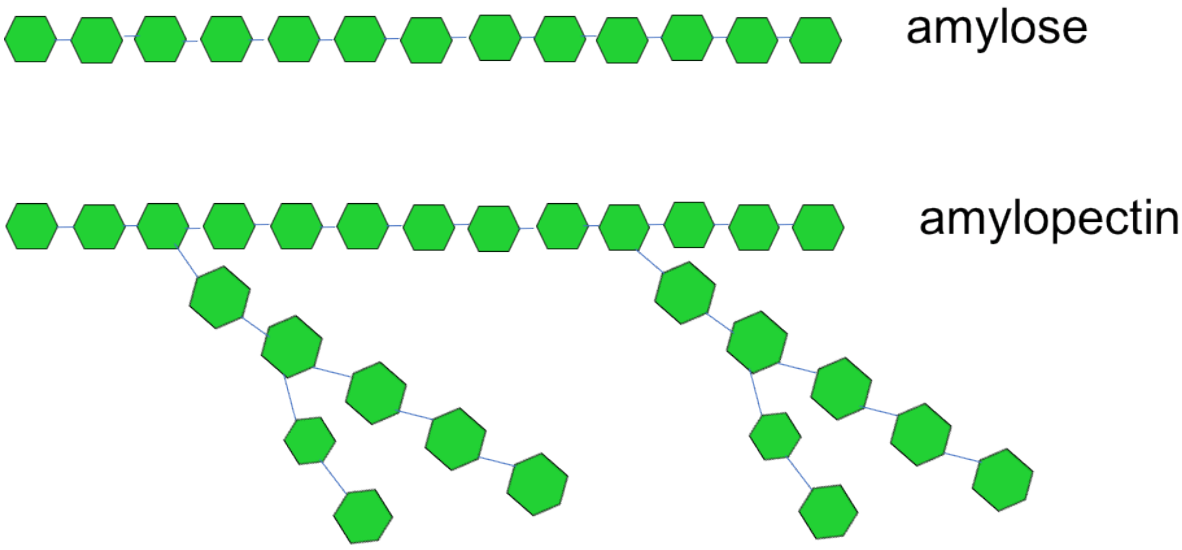
Here is an amylose segment containing 3 glucose units.



The next figure shows an amylopectin segment containing 4 glucose units. The chemical structure is represented differently, but can you spot the place where it branches?



Using our green hexagon to represent glucose, you can picture starch as something like this:



Humans have digestive enzymes to break down both types of starch, which we'll discuss on the next page.

Starch is the storage form of carbohydrate in plants. Plants make starch in order to store glucose. For example, starch is in seeds to give the seedling energy to sprout, and we eat those seeds in the form of grains, legumes (soybeans, lentils, pinto and kidney beans, for example), nuts, and seeds. Starch is also stored in roots and tubers to provide stored energy for the plant to grow and reproduce, and we eat these in the form of potatoes, sweet potatoes, carrots, beets, and turnips.

When we eat plant foods with starch, we can break it down into glucose to provide fuel for our body's cells. In addition, starch from whole plant foods comes packaged with other valuable nutrients. We also find refined starch—such as corn starch—as an ingredient in many processed foods, because it serves as a good thickener.

Glycogen

Glycogen is structurally similar to amylopectin, but **it's the storage form of carbohydrate in animals**, humans included. It's made up of highly branched chains of glucose, and it's stored in the liver and skeletal muscle. The branched structure of glycogen makes it easier to break down quickly to release glucose to serve as fuel when needed on short notice.

Liver glycogen is broken down to glucose, which is released into the bloodstream and can be used by cells around the body. Muscle glycogen provides energy only for muscle, to fuel activity. That can come in handy if you're being chased by a lion, or sprinting to make your bus!

Even though glycogen is stored in the liver and muscles of animals, we don't find it in meat, because it's broken down soon after slaughter. Thus, glycogen is not found in our food. Instead, we have to make it in our liver and muscle from glucose.

Here's a beautiful depiction of glycogen.

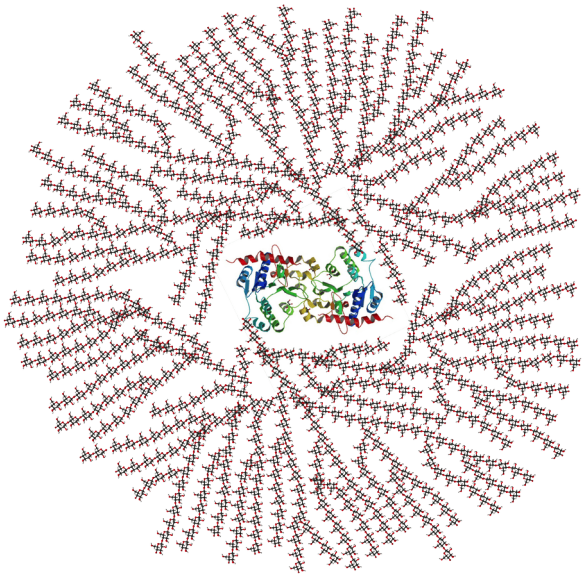


Figure 5.2.3: Glycogen is made from long, branching chains of glucose, radiating around a central protein.

Fiber

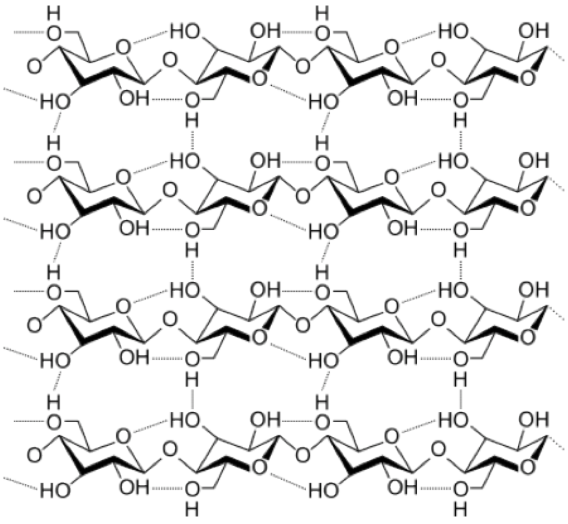
Fiber includes carbohydrates and other structural substances in plants that are indigestible to human enzymes. Fiber is made by plants to provide protection and structural support. Think about thick stems that help a plant stand upright, tough seed husks, and fruit skin that protect what's growing inside. These are full of fiber.

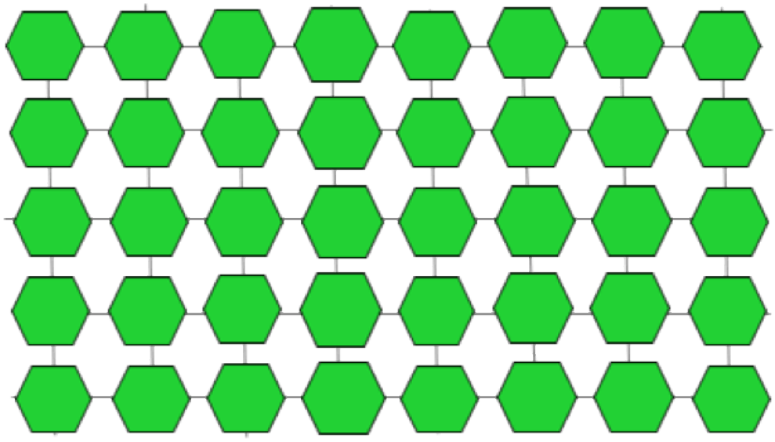


Figure 5.2.4: Examples of food plants high in fiber, including wheat, broccoli, and apples.

In our food, **we find fiber in whole plant foods** like whole grains, seeds, nuts, fruits, vegetables, and legumes.

One of the most common types of fiber is ***cellulose***, the main component in plant cell walls. The chemical structure of cellulose is shown in the figure below, with our simplified depiction next to it. You can see that cellulose has long chains of glucose, similar to starch, but they're stacked up, and there are hydrogen bonds linking the stacks.





When we eat fiber, it passes through the small intestine intact, because we don't have digestive enzymes to break it down. Then, in the large intestine, our friendly microbiota—the bacteria that live in our colons—go to work on the fiber. Some fiber can be fermented by those bacteria. We'll discuss fiber more later in the unit.

References:

- Levin, R. J. (1999). Carbohydrates. In Modern Nutrition in Health and Disease (9th ed.). Baltimore: Lippincott Williams and Wilkins.
- U.S. Department of Agriculture. (n.d.). FoodData Central. Retrieved November 15, 2019, from https://fdc.nal.usda.gov/

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5.3: Carbohydrate Food Sources and Guidelines for Intake

Where do we find carbohydrates in foods?

Looking at the food groups represented in MyPlate below, which food groups do you think contain carbohydrates? If you answered, all of them, you're correct! This section will review which food groups contain the different types of carbohydrates. One of the goals of this course is to learn more about the different nutrients in foods and to understand the importance of eating a wide variety of foods from the different food groups.

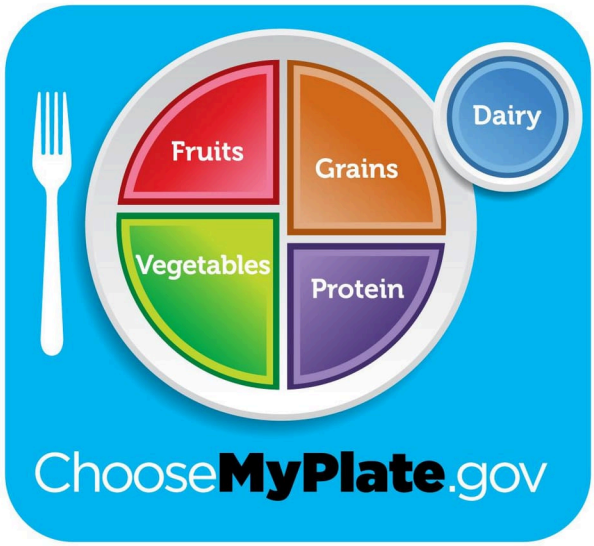


Figure 5.3.1: Choose MyPlate graphic illustrating the USDA food groups: fruits, vegetables, grains, protein and dairy.

Fruits– Fruits are sweet, so we know they must contain sugar. Fruits contain sucrose, glucose, and fructose. This sugar is naturally-occurring and comes packaged with other great nutrients, like Vitamin C and potassium. Whole fruit also contains fiber, since fiber is found in all whole plant foods. Juice has little to no fiber, even high pulp orange juice.

Vegetables– Some vegetables are sweet and also contain sugar, although much less than fruit. Similar to fruits, some vegetables (like carrots and green beans) contain small amounts of sucrose, glucose, and fructose. Starchy vegetables (corn, peas, and potatoes, for example) primarily contain starch but some are also sweet and contain sucrose, glucose, and fructose (sweet potatoes and sweet corn, for example). Just like whole fruit, any whole vegetable also contains fiber.

Grains– Grains naturally contain starch and fiber. Sprouted grains also contain maltose. If grains are sweetened (sugar is added), they might contain sucrose (white cane sugar) or fructose and glucose (honey and/or HFCS).

Dairy- This is the one animal food that contains carbohydrate. Milk, cheese, and yogurt contain naturally-occurring lactose. If dairy (like yogurt) is sweetened, then it will also contain added sugar like sucrose (white cane sugar) or fructose and glucose (honey and/or HFCS).

Protein– Meats do not contain carbohydrate, but many plant foods that fall into the protein group, like beans and nuts, contain starch and fiber.

Fats– Concentrated fats like butter and oil do not contain carbohydrate.

This information is summarized in the table below:

Food Group	Example of Food	Type of Carbohydrate Present
Fruits	Apple, orange, banana Orange juice	Sucrose, glucose, fructose, and fiber Sucrose, glucose, fructose
Vegetables	Non-starchy veggies Starchy veggies (corn, potatoes, sweet potatoes, peas)	Sucrose, glucose, fructose, and fiber Starch and fiber, with varying amount of sucrose, glucose, and fructose
Dairy	Milk, plain yogurt, cheese	Lactose
Grains	Wheat, rice, oatmeal, barley Sprouted grains	Starch and fiber Starch, fiber, and maltose
Protein	Meat Beans and nuts	None Starch and fiber
Fats	Oils, Butter	None

Table 5.3.1: *USDA food groups with examples of foods and type of carbohydrate present within each food group.*

Looking at all the foods that contain carbohydrates, you might be able to guess why eliminating carbohydrates from the diet can lead to weight loss. It drastically reduces the variety of choices one has, leaving you primarily with low carbohydrate veggies and meats. Not surprisingly, people usually consume less calories with this way of eating. However, for most people, this is not a sustainable or enjoyable way of eating, and it can also be hard to consume a nutritionally balanced diet with so many foods off-limits.

Carbohydrate Guidelines for Intake

Total Carbohydrate Intake

The recommended dietary allowance (RDA) for total carbohydrate intake is 130 grams. This is the minimum amount of glucose utilized by the brain, so if you consume less than this, you will probably go into ketosis. In order to meet the body's high energy demand for glucose, the acceptable macronutrient distribution range (AMDR) for an adult is 45%-65% of total calories. This is about 225 grams to 325 grams of carbohydrate per day if eating a 2,000 Calorie diet. (*REMEMBER: 1 gram of carbohydrate contains 4 calories.*)

Fiber Intake

The Adequate Intake (AI) for fiber is 14 grams of fiber for every 1,000 calories consumed. This is about 28 grams for an adult female (19-30 years old) and 38 grams for an adult male (19-30 years old). Most people in the United States only get half the amount of fiber they need in a day—about 12 to 18 grams.

Added Sugar Intake

The 2015 Dietary Guidelines recommend that less than 10% of total calories come from added sugars because of its link to obesity and chronic disease. This means that someone eating a 2,000 calorie diet would want to limit their added sugar intake to about 12 teaspoons per day. To put that in perspective, a 12 oz can of soda has about 10 teaspoons of sugar. We will discuss added sugar in more detail later in the unit.

Below is a chart summarizing the above recommendations.

Recommendations	
RDA for Total Carbohydrate	130 grams
AMDR for Total Carbohydrate	45% – 65% of total calories
AI for Fiber	14 grams for every 1,000 calories consumed
Dietary guidelines for added sugar	Less than 10% of total calories

Table 5.3.2: Dietary Recommendations for Carbohydrates

Resources:

- US Department of Health and Human Services and U.S. Department of Agriculture. (2015). Dietary Guidelines for Americans. Retrieved from https://health.gov/dietaryguidelines/2015/guidelines/
- Institute of Medicine, Food and Nutrition Board. (2005). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients). Retrieved from https://www.nap.edu/read/10490/chapter/1

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5.4: Digestion and Absorption of Carbohydrates



Imagine taking a bite of pizza. It tastes amazing, but it's also full of fuel for your body, much of it in the form of carbohydrates.

What types of carbohydrates would you find in that bite?

- Lactose from the cheese
- Sucrose, glucose, and fructose from the naturally-occurring sugars in the tomatoes, as well as sugar that may have been added to the sauce
- Starch in the flour used to make the crust
- Fiber in the flour, tomatoes, and basil

In order to use these food carbohydrates in your body, you first need to digest them. Last unit, we explored the gastrointestinal system and the basic process of digestion. Now that you know about the different types of carbohydrates, we'll take a closer look at how these molecules are digested as they travel through the GI system.

Carbohydrate Digestion

In the image below, follow the numbers to see what happens to carbohydrates at each site of digestion.

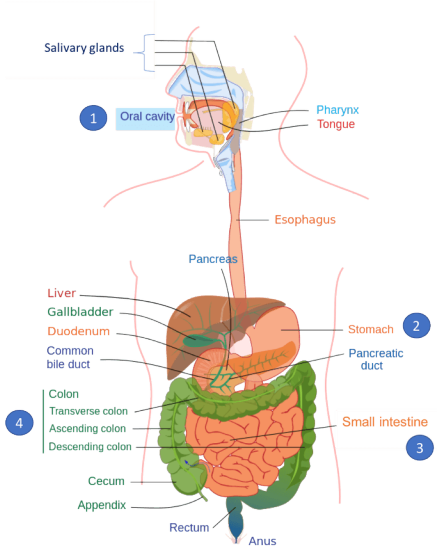


Figure 5.4.1: The digestive system (Copyright; author via source)

Mouth or Oral Cavity

As you chew your bite of pizza, you're using mechanical digestion to begin to break it into smaller pieces and mix it with saliva, produced by several salivary glands in the oral cavity.

Some enzymatic digestion of **starch** occurs in the mouth, due to the action of the enzyme ***salivary amylase***. This enzyme starts to break the long glucose chains of starch into shorter chains, some as small as maltose. (The other carbohydrates in the bread don't undergo any enzymatic digestion in the mouth.)

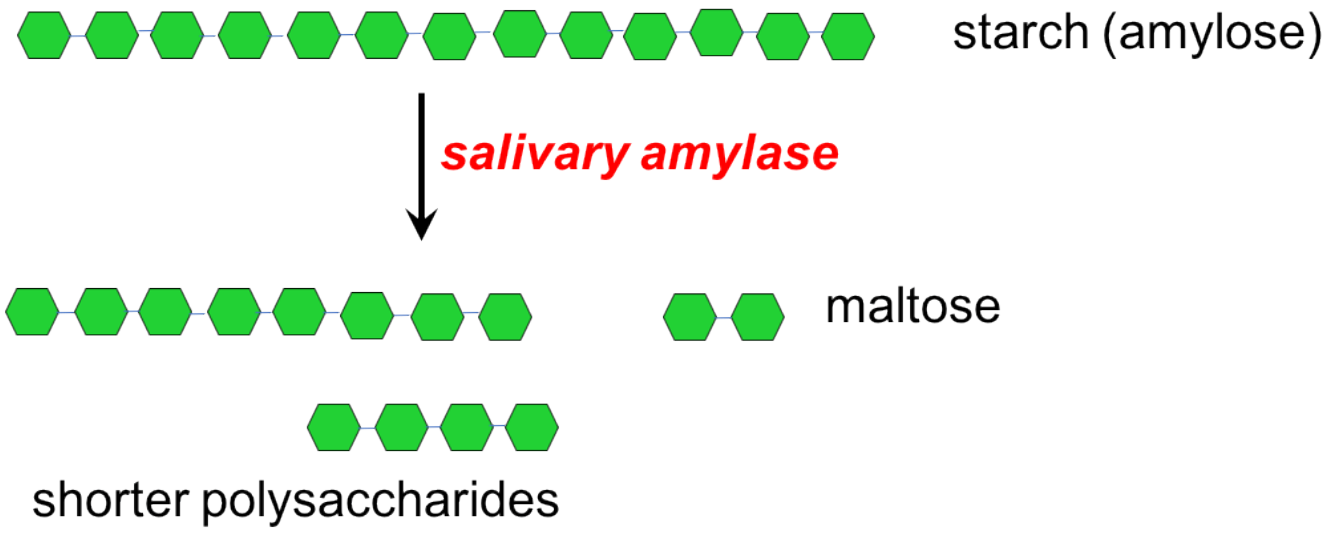


Figure 5.4.2: The enzyme salivary amylase breaks starch into smaller polysaccharides and maltose. (Copyright; author via source)

Stomach

The low pH in the stomach inactivates salivary amylase, so it no longer works once it arrives at the stomach. Although there's more mechanical digestion in the stomach, there's little chemical digestion of carbohydrates here.

Small intestine

Most carbohydrate digestion occurs in the small intestine, thanks to a suite of enzymes. ***Pancreatic amylase*** is secreted from the pancreas into the small intestine, and like salivary amylase, it breaks starch down to small oligosaccharides (containing 3 to 10 glucose molecules) and maltose.

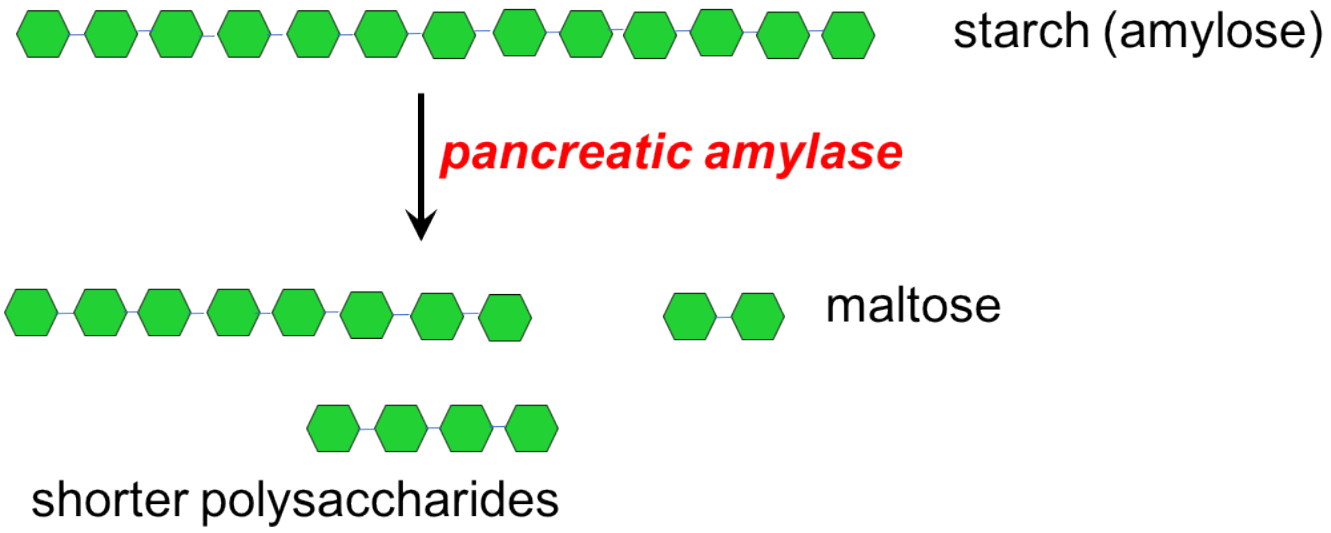


Figure 5.4.3: The enzyme pancreatic amylase breaks starch into smaller polysaccharides and maltose. (Copyright; author via source)

The rest of the work of carbohydrate digestion is done by enzymes produced by the enterocytes, the cells lining the small intestine. When it comes to digesting your slice of pizza, these enzymes will break down the maltose formed in the process of starch digestion, the lactose from the cheese, and the sucrose present in the sauce.

Maltose is digested by ***maltase***, forming 2 glucose molecules.



Lactose is digested by ***lactase***, forming glucose and galactose.



Sucrose is digested by ***sucrase***, forming glucose and fructose.

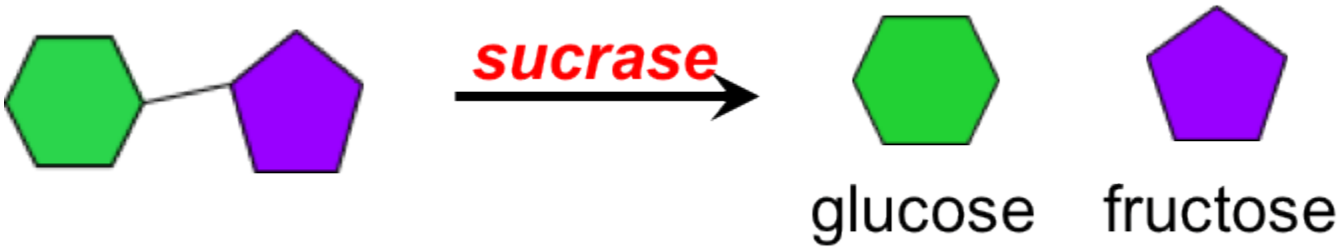


Figure 4.12. Action of the enzymes maltase, lactase, and sucrase.

(Recall that if a person is lactose intolerant, they don't make enough lactase enzyme to digest lactose adequately. Therefore, lactose passes to the large intestine. There it draws water in by osmosis and is fermented by bacteria, causing symptoms such as flatulence, bloating, and diarrhea.)

By the end of this process of enzymatic digestion, we're left with three monosaccharides: glucose, fructose, and galactose. These can now be absorbed across the enterocytes of the small intestine and into the bloodstream to be transported to the liver.

Digestion and absorption of carbohydrates in the small intestine are depicted in a very simplified schematic below. (*Remember that the inner wall of the small intestine is actually composed of large circular folds, lined with many villi, the surface of which are made up of microvilli. All of this gives the small intestine a huge surface area for absorption.*)

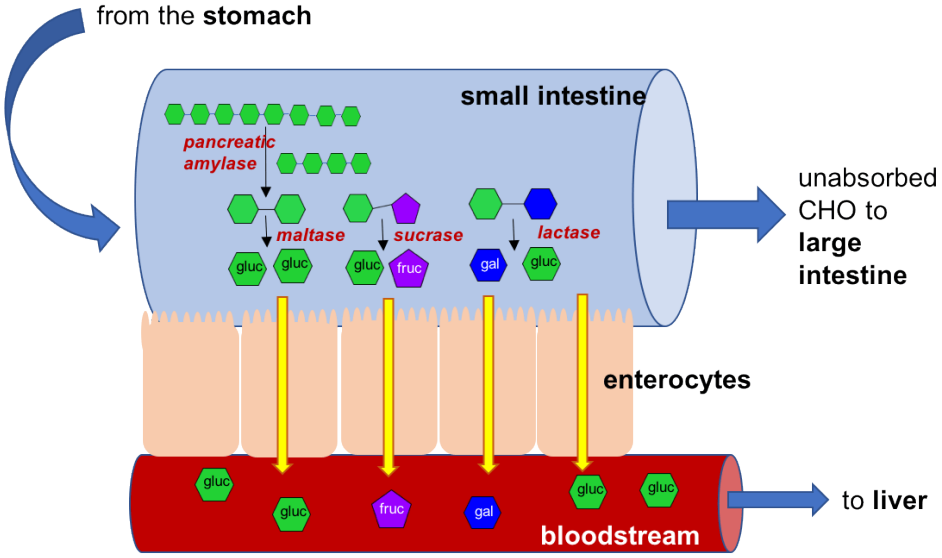


Figure 4.13. Digestion and absorption of carbohydrates in the small intestine.

Fructose and galactose are converted to glucose in the liver. Once absorbed carbohydrates pass through the liver, glucose is the main form of carbohydrate circulating in the bloodstream.

Large Intestine or Colon

Any carbohydrates that weren't digested in the small intestine—mainly fiber—pass into the large intestine, but there's no enzymatic digestion of these carbohydrates here. Instead, bacteria living in the large intestine, sometimes called our gut microbiota, ferment these carbohydrates to feed themselves. Fermentation causes gas production, and that's why we may experience bloating and flatulence after a particularly fibrous meal. Fermentation also produces short-chain fatty acids, which our large intestine cells can use as an energy source. Over the last decade or so, more and more research has shown that our gut microbiota are incredibly important to our health, playing important roles in the function of our immune response, nutrition, and risk of disease. A diet high in whole food sources of fiber helps to maintain a population of healthy gut microbes.

Summary of Carbohydrate Digestion:

The primary goal of carbohydrate digestion is to break polysaccharides and disaccharides into monosaccharides, which can be absorbed into the bloodstream.

1. After eating, nothing needs to happen in the digestive tract to the monosaccharides in a food like grapes, because they are already small enough to be absorbed as is.
2. Disaccharides in that grape or in a food like milk are broken down (enzymatically digested) in the digestive tract to monosaccharides (glucose, galactose, and fructose).
3. Starch in food is broken down (enzymatically digested) in the digestive tract to glucose molecules.
4. Fiber in food is not enzymatically digested in the digestive tract, because humans don't have enzymes to do this. However, some dietary fiber is fermented in the large intestine by gut microbes.

Carbohydrates in food	**Is this carbohydrate enzymatically digested?** *(enzyme name)*	**What is absorbed into the villi after digestion?**
Monosaccharides		
Glucose	No	Glucose
Fructose	No	Fructose. It is then transported to the liver where it is converted to glucose.
Galactose	No	Galactose. It is then transported to the liver where it is converted to glucose.
Disaccharides		
Maltose	Yes *(maltase)*	Glucose
Sucrose	Yes *(sucrase)*	Glucose, Fructose
Lactose	Yes *(lactase)*	Glucose, Galactose
Polysaccharides		
Starch	Yes *(amylase, maltase)*	Glucose

Fiber	No *(Humans don't have the digestive enzymes to break down fiber, but some is fermented by gut microbes in the large intestine.)*	N/A

Table 4.3. Summary of enzymatic digestion of carbohydrates

VIDEO: "Digestion and Absorption of Carbohydrates" by How It Works.

YouTube Video

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View this YouTube Video online

VIDEO: "Carbohydrates in Foods, Digestion and Absorption" by Tamberly Powell, YouTube (September 26, 2018), 7:31 minutes. This video will help you identify carbohydrates in foods, what carbohydrates need to be enzymatically digested, and what is absorbed.

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5.5: Glucose Regulation and Utilization in the Body

On the last page, we traced the process of digesting the carbohydrates in a slice of pizza through the gastrointestinal tract, ending up with the absorption of monosaccharides across the cells of the small intestine and into the bloodstream. From there, they travel to the liver, where fructose and galactose are converted to glucose.

After any meal containing carbohydrates, you experience a rise in blood glucose that can serve as fuel for cells around the body. But during the periods between meals, including while you're sleeping and exercising, your body needs fuel, too. To ensure that you have enough glucose in your blood at any given time, your body has a finely-tuned system to regulate your blood glucose concentration. This system allows you to store glucose when you have excess available (when your blood glucose is high) and to pull glucose out from your stores when needed (when your blood supply gets low).

Your body's ability to maintain equilibrium or a steady state in your blood glucose concentration is called ***homeostasis***. It's a critical part of normal physiology, because if your blood glucose gets too low (called ***hypoglycemia***), cellular function starts to fail, especially in the brain. If blood glucose gets too high (called ***hyperglycemia***), it can cause damage to cells.

Hormones Involved in Blood Glucose Regulation

Central to maintaining blood glucose homeostasis are two hormones, ***insulin*** and ***glucagon***, both produced by the pancreas and released into the bloodstream in response to changes in blood glucose.

- **Insulin** is made by the beta-cells of the pancreas and released when **blood glucose is high**. It causes cells around the body to take up glucose from the blood, resulting in lowering blood glucose concentrations.
- **Glucagon** is made by the alpha-cells of the pancreas and released when **blood glucose is low**. It causes glycogen in the liver to break down, releasing glucose into the blood, resulting in raising blood glucose concentrations. (Remember that glycogen is the storage form of glucose in animals.)

The image below depicts a mouse islet of Langerhans, a cluster of endocrine cells in the pancreas. The beta-cells of the islet produce insulin, and the alpha-cells produce glucagon.

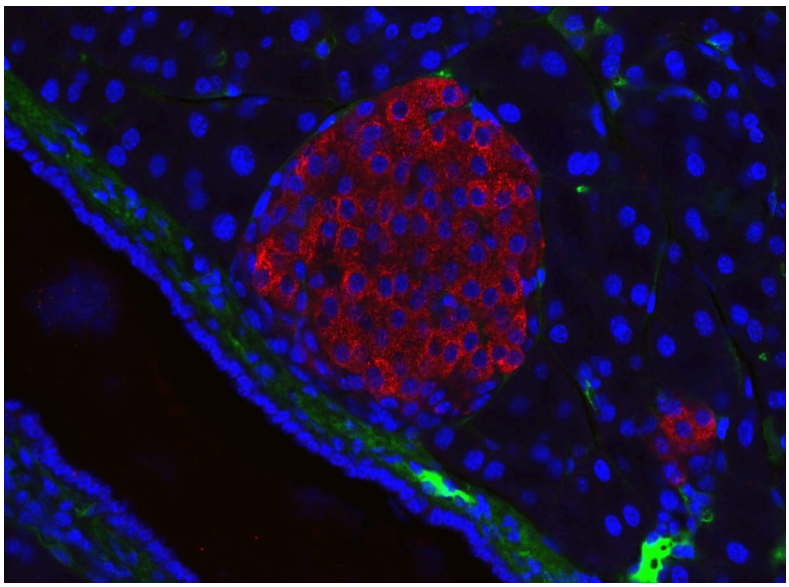


Figure 5.5.1: A mouse islet of Langerhans, visualized with immunofluorescent microscopy. In this image, cell nuclei are stained blue, insulin is stained red, and blood vessels are stained green. You can see that this islet is packed with insulin and sits right next to a blood vessel, so that it can secrete the two hormones, insulin and glucagon, into the blood. Glucagon is not stained in this image, but it's there!

In the figure below, you can see blood glucose and insulin throughout a 24-hour period, including three meals. You can see that when glucose rises, it is followed immediately by a rise in insulin, and glucose soon drops again. The figure also shows the

difference between consuming a sucrose-rich food and a starch-rich food. The sucrose-rich food results in a greater spike in both glucose and insulin. Because more insulin is required to handle that spike, it also causes a more precipitous decline in blood glucose. This is why eating a lot of sugar all at once may increase energy in the short-term, but soon after may make you feel like taking a nap!

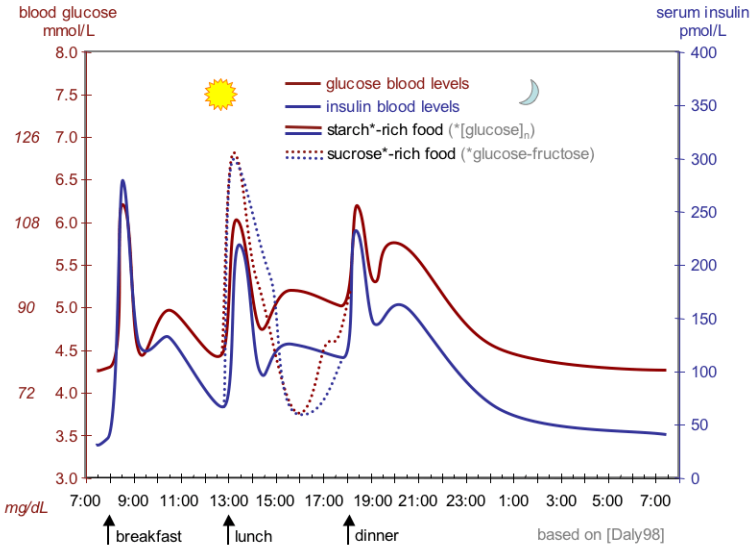


Figure 5.5.2: Typical pattern of blood glucose and insulin during a 24-hour period, showing peaks for each of 3 meals and highlighting the effects of consumption of sugar-rich foods.

Let's look a little closer at how insulin works, illustrated in the figure below. Insulin is released by the pancreas into the bloodstream. Cells around the body have receptors for insulin on their cell membranes. Insulin fits into its receptors (labeled as step 1 in Figure 4.16), kind of like a key in a lock, and through a series of reactions (step 2), triggers glucose transporters to open on the surface of the cell (step 3). Now glucose can enter the cell, making it available for the cell to use and at the same time lowering the concentration of glucose in the blood.

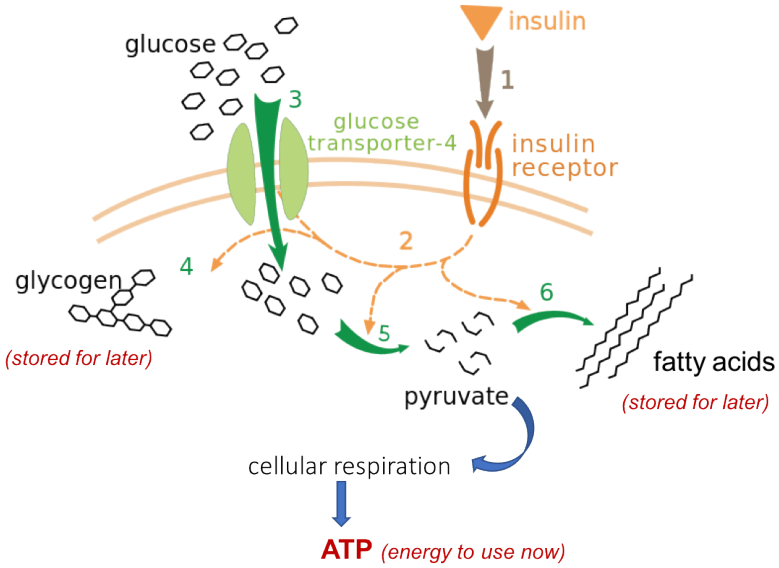


Figure 5.5.3: Insulin binds to its receptors on the cell membrane, triggering GLUT-4 glucose transporters to open on the membrane. This allows glucose to enter the cell, where it can be used in several ways.

The figure also shows several different ways glucose can be used once it enters the cell.

- If the cell needs energy right away, it can metabolize glucose through cellular respiration, producing ATP (step 5).
- If the cell doesn't need energy right away, glucose can be converted to other forms for storage. If it's a liver or muscle cell, it

can be converted to **glycogen** (step 4). Alternatively, it can be converted to **fat** and stored in that form (step 6).

In addition to its role in glucose uptake into cells, insulin also stimulates glycogen and fat synthesis as described above. It also stimulates protein synthesis. You can think of its role as signaling to the body that there's lots of energy around, and it's time to use it and store it in other forms.

On the other hand, when blood glucose falls, several things happen to restore homeostasis.

1. You receive messages from your brain and nervous system that **you should eat**.
2. Glucagon is released from the pancreas into the bloodstream. In liver cells, it stimulates the **breakdown of glycogen**, releasing glucose into the blood.
3. In addition, glucagon stimulates a process called ***gluconeogenesis***, in which new glucose is made from amino acids (building blocks of protein) in the liver and kidneys, also contributing to raising blood glucose.

How Glucose Provides Energy

Now let's zoom in on how exactly glucose provides energy to the cell. We can trace this process in the figure below.

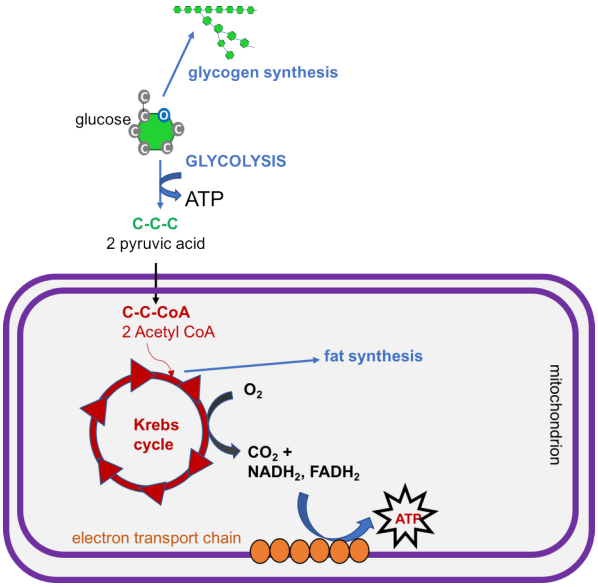


Figure 5.5.4: Overview of glucose metabolism in the fed state, when there is adequate glucose available. Glucose can be used to generate ATP for energy, or it can be stored in the form of glycogen or converted to fat for storage in adipose tissue.

1. Glucose, a 6-carbon molecule, is broken down to two 3-carbon molecules called ***pyruvate*** through a process called ***glycolysis***.
2. Pyruvate enters a mitochondrion of the cell, where it is converted to a molecule called ***acetyl CoA***.
3. Acetyl CoA goes through a series of reactions called the ***Krebs cycle***. This cycle requires oxygen and produces carbon dioxide. It also produces several important high energy electron carriers called $NADH_2$ and $FADH_2$.
4. These high energy electron carriers go through the electron transport chain to produce ATP—energy for the cell!
5. Note that the figure also shows that glucose can be used to synthesize glycogen or fat, if the cell already has enough energy.

What Happens When There Isn't Enough Glucose?

We've already talked about what happens when blood glucose falls: glucagon is released, and that stimulates the breakdown of glycogen as well as the process of gluconeogenesis from amino acids. These are important mechanisms for maintaining blood glucose levels to fuel the brain when carbohydrate is limited. **Hypoglycemia** (low blood glucose) can cause you to feel confused, shaky, and irritable, because your brain doesn't have enough glucose. If it persists, it can cause seizures and eventually coma, so it's good we have these normal mechanisms to maintain blood glucose homeostasis!

What happens if your carbohydrate supply is limited for a long time? This might happen if a person is starving or consuming a

very low carbohydrate diet. In this case, your glycogen supplies will become depleted. How will you get enough glucose (especially for the brain) and energy? You'll have to use the other two macronutrients in the following ways:

1. **Protein:** You'll continue to use some amino acids to make glucose through gluconeogenesis and others as a source of energy through acetyl CoA. However, if a person is starving, they also won't have extra dietary protein. Therefore, they start breaking down body proteins, which will cause muscle wasting.
2. **Fat:** You can break down fat as a source of energy, but you can't use it to make glucose. Fatty acids can be broken down to acetyl CoA in the liver, but acetyl CoA can't be converted to pyruvate and go through gluconeogenesis. It can go through the Krebs cycle to produce ATP, but if carbohydrate is limited, the Krebs cycle gets overwhelmed. In this case, acetyl CoA is converted to compounds called ***ketones*** or ***ketone bodies***. These can then be exported to other cells in the body, especially brain and muscle cells.

These pathways are shown in the figure below:

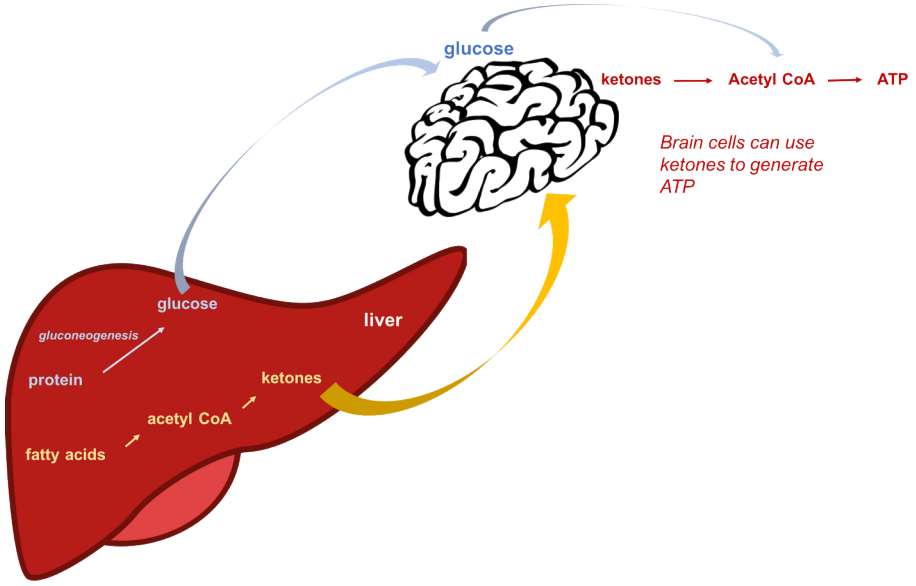


Figure 5.5.5: During starvation or when consuming a low-carbohydrate diet, protein (amino acids) can be used to make glucose by gluconeogenesis, and fats can be used to make ketones in the liver. The brain can adapt to using ketones as an energy source in order to conserve protein and prevent muscle wasting.

Ketone production is important, because ketones can be used by tissues of the body as a source of energy during starvation or a low carbohydrate diet. Even the brain can adapt to using ketones as a source of fuel after about three days of starvation or very low-carbohydrate diet. This also helps to preserve the protein in the muscle.

Ketones can be excreted in urine, but if ketone production is very high, they begin to accumulate in the blood, a condition called ***ketosis***. Symptoms of ketosis include sweet-smelling breath, dry mouth, and reduced appetite. People consuming a very low carbohydrate diet may be in ketosis, and in fact, this is a goal of the currently popular ketogenic diet. (Ketones are acidic, so severe ketosis can cause the blood to become too acidic, a condition called ***ketoacidosis***. This mainly happens with uncontrolled diabetes.)

Is following a ketogenic diet an effective way to lose weight? It can be, but the same can be said of any diet that severely restricts the types of foods that you're allowed to eat. Following a ketogenic diet means eating a high fat diet with very little carbohydrate and moderate protein. This means eating lots of meat, fish, eggs, cheese, butter, oils, and low carbohydrate vegetables, and eliminating grain products, beans, and even fruit. With so many fewer choices, you're likely to spend more time planning meals and less time mindlessly snacking. Being in ketosis also seems to reduce appetite, and it causes you to lose a lot of water weight initially. However, studies show that being in ketosis doesn't seem to increase fat-burning or metabolic rate. There are also concerns that the high levels of saturated fat in most ketogenic diets could increase risk of heart disease in the long term. Finally, it's a very difficult diet to maintain for most people, and reverting back to your previous dietary patterns usually means the weight will come back. The ketogenic diet is also very similar to the Atkins diet that was all the rage in the 1990's, and we tend to be skeptical of such fad diets, preferring to focus instead on balance, moderation, and enjoyment of a wide variety of foods.

YouTube Video

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Video: "Glucose Regulation and Utilization in the Body," by Alice Callahan, YouTube (October 1, 2018), 13:11 minutes.

Diabetes

Diabetes is a chronic disease in which your normal system of regulating blood glucose doesn't work. There are three main types of diabetes: type 1, type 2, and gestational diabetes.

Type 1 Diabetes:

This is an autoimmune disease in which the beta-cells of the pancreas are destroyed by your own immune system. Without the beta-cells, you can't make enough insulin, so in ***type 1 diabetes***, you simply don't have enough insulin to regulate your blood glucose levels. Remember how we said insulin is like the key that lets glucose into the body's cells? In type 1 diabetes, you're missing the key, so glucose stays in the blood and can't get into cells.

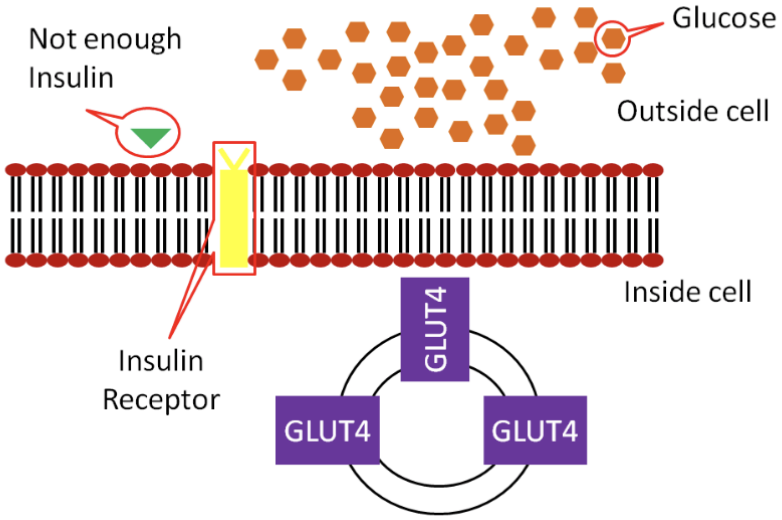


Figure 5.5.6: In type 1 diabetes, the pancreas does not make enough insulin, so glucose transporters (GLUT-4) do not open on the cell membrane, and glucose is stuck outside the cell.

Common symptoms include weight loss and fatigue, because the body's cells are starved of glucose. Excess glucose from the blood is also excreted in the urine, increasing urination and thirst.

Once diagnosed, type 1 diabetics have to take insulin in order to regulate their blood glucose. Traditionally, this has required insulin injections timed with meals. New devices like continuous glucose monitors and automatic insulin pumps can track glucose levels and provide the right amount of insulin, making managing type 1 diabetes a little easier. Figuring out the right amount of insulin is important, because chronically elevated blood glucose levels can cause damage to tissues around the body. However, too much insulin will cause **hypoglycemia**, which can be very dangerous.

Type 1 diabetes is most commonly diagnosed in childhood, but it has been known to develop at any age. It's much less common than type 2 diabetes, accounting for 5-10% of cases of diabetes.

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View this YouTube Video online

Video: "What is Type 1 Diabetes?" by Diabetes UK, YouTube (April 10, 2018), 2:27 minutes.

Type 2 Diabetes:

Development of ***type 2 diabetes*** begins with a condition called ***insulin resistance***. At least initially, the pancreas is producing enough insulin, but the body's cells don't respond appropriately. It's as if you still have the insulin key but can't find the keyhole to unlock the doors and let the glucose in.

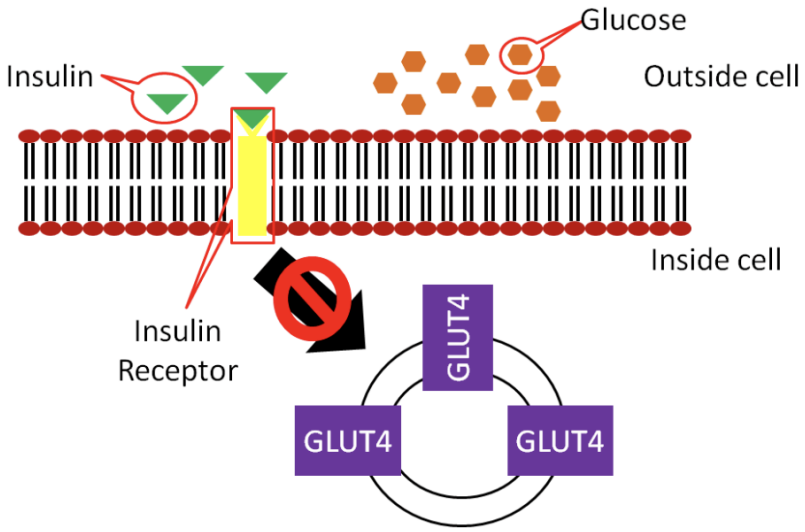


Figure 5.5.7: In type 2 diabetes, the cell does not respond appropriately to insulin, so glucose is stuck outside the cell.

The result is the same: high blood glucose. At this point, you may be diagnosed with a condition called ***prediabetes***. The pancreas tries to compensate by making more insulin, but over time, it becomes exhausted and eventually produces less insulin, leading to full-blown type 2 diabetes. According to the CDC, 100 million Americans are living with diabetes (30.3 million) or prediabetes (84.1 million).

Although people of all shapes and sizes can get Type 2 diabetes, it is strongly associated with abdominal obesity. In the past, it was mainly diagnosed in older adults, but it is becoming more and more common in children and adolescents as well, as obesity has increased in all age groups. In the maps below, you can see that as obesity has increased in states around the country, so has diabetes.

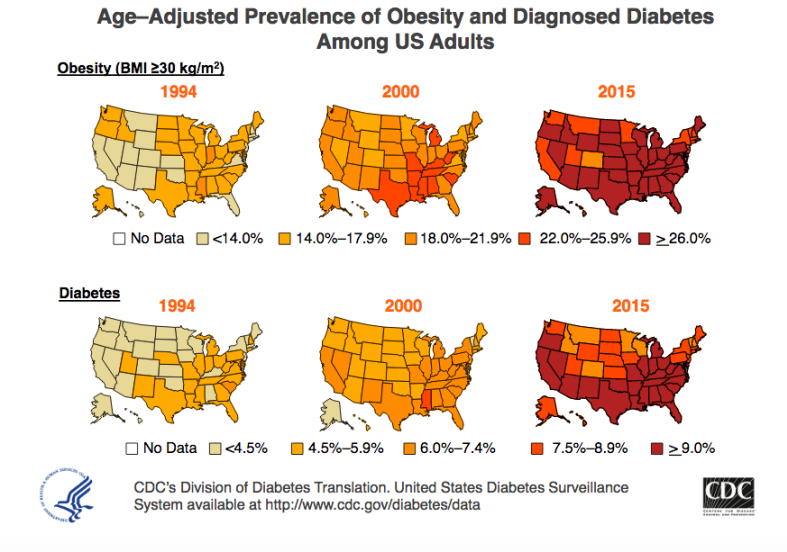


Figure 5.5.8: Data from the CDC show the increasingly prevalence of both obesity and type 2 diabetes between 1994 and 2015.

The complications of type 2 diabetes result from long-term exposure to high blood glucose, or hyperglycemia. This causes damage to the heart, blood vessels, kidneys, eyes, and nerves, increasing the risk of heart disease and stroke, kidney failure, blindness, and nerve dysfunction. People with uncontrolled Type 2 diabetes can also end up with foot infections and ulcers because of impaired nerve function and wound healing. If left untreated, this results in amputation.

YouTube Video

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Video: "What is Type 2 Diabetes?" by Diabetes UK, YouTube (April 10, 2018), 2:36 minutes. This video reviews the causes, complications, and treatments for type 2 diabetes.

YouTube Video

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

View this YouTube Video online

Video: "Obesity and Type 2 Diabetes (HBO: The Weight of the Nation)", by HBO Docs, YouTube (May 14, 2012), 15:20 minutes.

Gestational diabetes:

Gestational diabetes is diabetes that develops during pregnancy in women that did not previously have diabetes. It affects approximately 6 percent of pregnancies in the U.S. It can cause pregnancy complications, mostly associated with excess fetal growth because of high blood glucose. Although it usually goes away once the baby is born, women who have gestational diabetes

are more likely to develop type 2 diabetes later in life, so it is a warning sign for them.[6]

YouTube Video

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View this YouTube Video online

Video: "Types of Diabetes" by KhanAcadamyMedicine, YouTube (May 14, 2015), 5:57 minutes. This video does a nice job of explaining the causes of the different types of diabetes.

Diabetes Management:

All of the following have been shown to help manage diabetes and reduce complications. Diabetes management, as well as prevention (particularly if you've been diagnosed with prediabetes), starts with lifestyle choices.

- **Exercise** helps to improve your body's insulin response and can also help maintain a healthy weight.
- **Eating well** with diabetes doesn't require a special diet but instead regular, balanced meals following the Dietary Guidelines. It isn't necessary to eliminate carbohydrates or eat a low-carbohydrate diet, but emphasizing whole food sources of carbohydrate helps with blood glucose regulation.
- **Managing stress levels** and **getting enough sleep** can also help with blood glucose regulation.
- **Medications** may be needed. Insulin is needed for type 1 diabetes and may be needed for more advanced or severe cases of type 2 or gestational diabetes. Other medications can also help. If lifestyle choices aren't enough to manage diabetes, it is important to use medications appropriately to help reduce the complications of chronic high blood glucose.

Considerations for Transgender and Gender-diverse Individuals

On the biochemical and clinical lab side, evaluators should include markers of metabolic health (e.g., glucose, insulin, liver enzymes). Over time, clinicians should monitor bone density especially in those receiving gonadal suppression or inconsistent hormone dosing.

Gender-affirming nutrition care demands flexibility: selecting or blending reference values based on hormonal state, tracking body composition changes rather than overreliance on rigid cutoffs, and anchoring nutrient recommendations in individualized lab data. Because the evidence base remains limited, ongoing data collection, research, and shared decision-making with clients are foundational to advancing best practice in this domain (Sousa et al., 2023; Gold et al., 2024).

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5.6: Fiber - Types, Food Sources, Health Benefits, and Whole vs. Refined Grains

Dietary fiber is defined by the Institute of Medicine's Food and Nutrition Board as "nondigestible carbohydrates and lignin that are intrinsic and intact in plants." Fiber plays an important role in giving plants structure and protection, and it also plays an important role in the human diet.

Cellulose is one type of fiber. The chemical structure of cellulose is shown in the figure below, with our simplified depiction next to it. You can see that cellulose has long chains of glucose, similar to starch, but they're stacked up, and there are hydrogen bonds linking the stacks. The special bonds between these glucose units in fiber are not enzymatically digested in the digestive tract, and therefore, **fiber passes undigested to the colon** or large intestine.

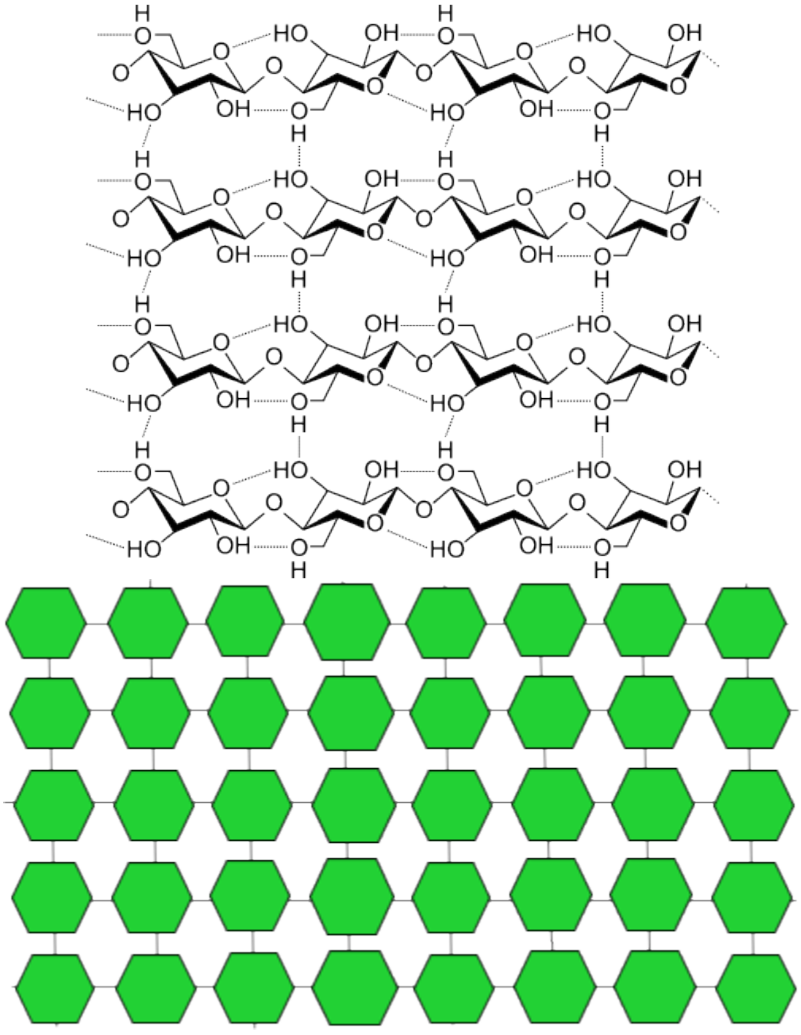


Figure 4.22. The chemical structure of cellulose, and a simplified illustration of cellulose.

You might be wondering how fiber has any benefit to us if we can't digest it. However, it doesn't just pass through the digestive tract as a waste product. Instead, it serves many functions on its journey, and these contribute to our health. Let's explore the different types of fiber, where we find them in foods, and what benefits they provide!

Types of Fiber

Whole plant foods contain many different types of molecules that fit within the definition of fiber. One of the ways that types of fiber are classified is by their solubility in water. Whole plant foods contain a mix of both soluble and insoluble fiber, but some are better sources of one than the other.

1. **Soluble Fiber** – These fibers dissolve in water, forming a viscous gel in the GI tract, which helps to slow digestion and the absorption of glucose. This means that including soluble fiber in a meal helps to prevent sharp blood sugar spikes, instead making for a more gradual rise in blood glucose. Consuming a diet high in soluble fiber can also help to lower blood cholesterol levels, because soluble fiber binds cholesterol and bile acids (which contain cholesterol) in the GI tract. Soluble fiber is also highly fermentable, so it is easily digested by bacteria in the large intestine. Pectins and gums are common types of soluble fibers, and good food sources include oat bran, barley, nuts, seeds, beans, lentils, peas, and some fruits and vegetables. (Psyllium fiber supplements like Metamucil are composed mainly of soluble fiber, so if you've ever stirred a spoonful of this into a glass of water, you've seen the viscous consistency characteristic of soluble fiber.)
2. **Insoluble Fiber** – These fibers typically do not dissolve in water and are nonviscous. Some are fermentable by bacteria in the large intestine but to a lesser degree than soluble fibers. Insoluble fibers help prevent constipation, as they create a softer, bulkier stool that is easier to eliminate. Lignin, cellulose, and hemicellulose are common types of insoluble fibers, and food sources include wheat bran, vegetables, fruits, and whole grains.

Food Sources of dietary fiber

Since fiber provides structure to plants, **fiber can be found in all whole plant foods**, including whole grains (like oatmeal, barley, rice and wheat), beans, nuts, seeds, and whole fruits and vegetables.



Figure 4.23. A bowl of oatmeal topped with blueberries and sunflower seeds.

This meal is packed with fiber from the oatmeal, blueberries, and sunflower seeds.

When foods are refined, parts of the plant are removed, and during this process, fiber and other nutrients are lost. For example, fiber is lost when going from a whole fresh orange to orange juice. A whole orange contains about 3 grams of fiber, whereas a glass of orange juice has little to no fiber. Fiber is also lost when grains are refined. We will discuss this more a little later.

Take a look at the list of foods below to see the variety of foods which provide dietary fiber.

Food	Standard Portion Size	Calories in Standard Portion	Dietary Fiber in Standard Portion (g)
Shredded wheat ready-to-eat cereal (various)	1-1 ¼cup	155-220	5.0-9.0
Wheat bran flakes ready-to-eat cereal (various)	¾ cup	90-98	4.9-5.5
Lentils, cooked	½ cup	115	7.8
Black beans, cooked	½ cup	114	7.5
Refried beans, canned	½ cup	107	4.4
Avocado	½ cup	120	5.0
Pear, raw	1 medium	101	5.5
Pear, dried	¼ cup	118	3.4
Apple, with skin	1 medium	95	4.4
Raspberries	½ cup	32	4.0
Mixed vegetables, cooked from frozen	½ cup	59	4.0
Potato, baked, with skin	1 medium	163	3.6
Pumpkin seeds, whole, roasted	1 ounce	126	5.2
Chia seeds, dried	1 Tbsp	58	4.1
Sunflower seed kernels, dry roasted	1 ounce	165	3.1

Almonds	1 ounce	164	3.5
Plain rye wafer crackers	2 wafers	73	5.0
Bulgur, cooked	½ cup	76	4.1
Popcorn, air-popped	3 cups	93	3.5
Whole wheat spaghetti, cooked	½ cup	87	3.2
Quinoa, cooked	½ cup	111	2.6

Table 4.4. Common foods listed with standard portion size, and calories and fiber in a standard portion.

Although you can get fiber from supplements, whole foods are are a better source, because the fiber comes packaged with other essential nutrients and phytonutrients.

Health Benefits of Dietary Fiber

A high-fiber diet has many benefits, which include:

- **Helps prevent constipation.** Many fibers (but mostly insoluble fibers) help provide a softer, bulkier stool which is then easier to eliminate.
- **Helps maintain digestive and bowel health.** Dietary fiber promotes digestive health through its role in supporting elimination and fermentation, and it's positive impact on gut microbiota. Since fiber provides a bulkier stool, this helps keeps the digestive tract muscles toned and strong which can help prevent hemorrhoids and diverticula.
- **Lowers risk of cardiovascular disease.** Higher fiber intake has been shown to improve blood lipids by reducing total cholesterol, triglycerides, and low density cholesterol ("bad cholesterol," associated with a higher risk of cardiovascular disease), and increasing high density cholesterol ("good cholesterol," associated with lower risk of cardiovascular disease). Higher fiber intake has also been associated with lower blood pressure and reduced inflammation.
- **Lowers risk of type 2 Diabetes.** Higher fiber intake (especially viscous, or soluble fibers) has been shown to slow down glucose digestion and absorption, benefiting glucose metabolism. A higher fiber diet may also decrease diabetes risk by reducing inflammation.
- **Lowers risk of colorectal cancer.** More evidence is supporting the idea that higher fiber intake lowers the risk of colorectal cancer, although researchers aren't sure why. One hypothesis is that dietary fiber decreases transit time (the time it takes for food to move through the digestive tract), thereby exposing the cells of the gastrointestinal tract to carcinogens from food for a shorter time.
- **Helps maintain a healthy body weight.** Research has shown a relationship between higher dietary fiber intake and lower body weight. The mechanisms for this are unclear, but perhaps high-fiber foods are more filling and therefore keep people satisfied longer with fewer calories. High-fiber foods also tend to be more nutrient-dense compared to many processed foods, which are more energy-dense.

Whole vs. Refined Grains



Figure 4.24. Wheat growing in a field.

Before they are harvested, all grains are whole grains. They contain the entire seed (or kernel) of the plant. This seed is made up of three edible parts: the bran, the germ, and the endosperm. The seed is also covered by an inedible husk that protects the seed.

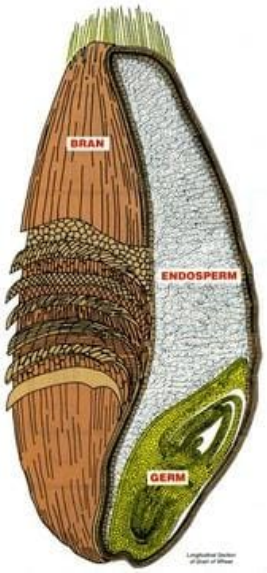


Figure 4.25. The anatomy of a wheat kernel which includes the bran, endosperm, and germ.

1. The ***bran*** is the outer skin of the seed. It contains antioxidants, B vitamins and fiber.
2. The ***endosperm*** is by far the largest part of the seed and provides energy in the form of starch to support reproduction. It also contains protein and small amounts of vitamins and minerals.
3. The ***germ*** is the embryo of the seed—the part that can sprout into a new plant. It contains B vitamins, protein, minerals like zinc and magnesium, and healthy fats.

The Dietary Guidelines for Americans define whole grains and refined grains in the following way:

"*Whole Grains*—Grains and grain products made from the entire grain seed, usually called the kernel, which consists of the bran, germ, and endosperm. If the kernel has been cracked, crushed, or flaked, it must retain the same relative proportions of bran, germ, and endosperm as the original grain in order to be called whole grain. Many, but not all, whole grains are also sources of dietary fiber."

Whole grains include foods like barley, corn (whole cornmeal and popcorn), oats (including oatmeal), rye, and wheat. (For a more complete list of whole grains, check out the Whole Grain Council.)

**"*Refined Grains*—Grains and grain products with the bran and germ removed; any grain product that is not a whole-grain product. Many refined grains are low in fiber but enriched with thiamin, riboflavin, niacin, and iron, and fortified with folic acid."

Refined grains include foods like white rice and white flour. According to the Whole Grain Council, "Refining a grain removes about a quarter of the protein in a grain, and half to two thirds or more of a score of nutrients, leaving the grain a mere shadow of its original self."

Refined grains are often ***enriched*** with vitamins and minerals, meaning that some of the nutrients lost during the refining process are added back in after processing. However, many vitamins and minerals are not added back, and neither are the fiber, protein, and healthy fats found in whole grains. In the chart below you can see the differences in essential nutrients between whole wheat flour, refined wheat flour, and enriched wheat flour.

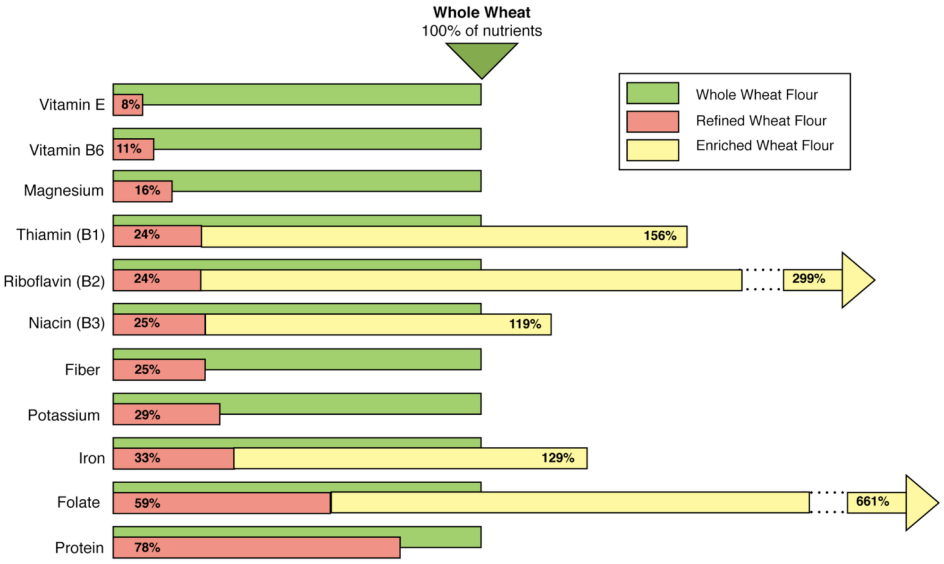


Figure 4.26. The nutrient content of refined wheat and enriched wheat as compared to whole wheat flour.

Because whole grains offer greater nutrient density, MyPlate and the Dietary Guidelines recommend that at least half of our grains are whole grains. Yet current data show that while most Americans are eating enough grains overall, they're eating too many refined grains and not enough whole grains, as shown in this graphic from the Dietary Guidelines:

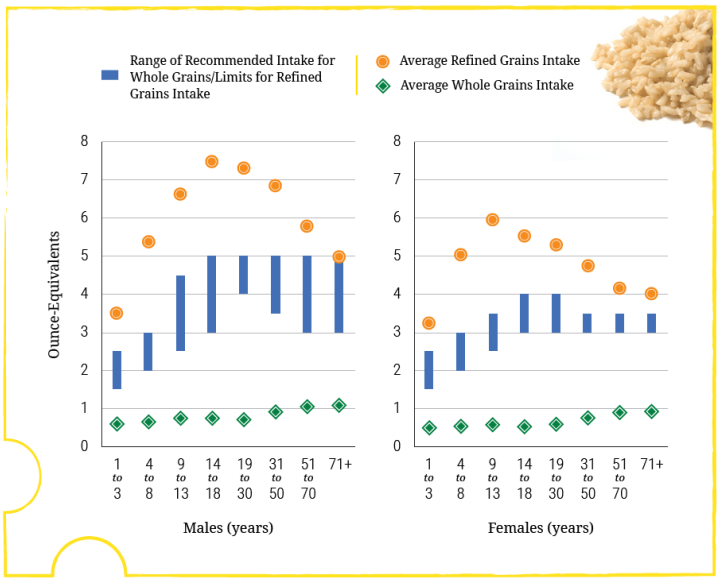


Figure 4.27. Average *Whole & Refined Grain Intakes in Ounce-Equivalents per Day by Age-Sex Groups, Compared to Ranges of Recommended Daily Intake for Whole Grains & Limits for Refined Grains.*

Looking for whole grain products at the grocery store can be tricky, since the front-of-package labeling is about marketing and selling products. Words like “made with whole grain” and “multigrain” on the front of the package make it appear like a product is whole grain, when in fact there may be very few whole grains present.

The color of a bread can be deceiving too. Refined grain products can have added caramel color to make them appear more like whole grains.

To determine if a product is a good source of whole grain, the best place to look is the ingredient list on the Nutrition Facts panel. The ingredients should list a whole grain as the first ingredient (e.g., 100% whole wheat), and it should not be followed by a bunch of refined grains such as enriched wheat flour.

Getting familiar with the name of whole grains will help you identify them. Common varieties include wheat, barley, brown rice, buckwheat, corn, rye, oats, and wild rice. Less known varieties include teff, amaranth, millet, quinoa, black rice, black barley, and spelt.

Most, but not all, whole grains are a good source of fiber, and that is one of the benefits of choosing whole grains. Keep in mind that some products add extra fiber as a separate ingredient, like wheat bran, inulin, or cellulose. These boost the grams of fiber on the Nutrition Facts label and may make the product a good source of fiber, but it doesn’t mean it’s a good source of whole grains. In fact, it may be a product made mostly of refined grains, so it would still be missing the other nutrients that come packaged in whole grains and may not have the same health benefits. Therefore, just looking at fiber on the Nutrition Facts label is not a good indicator of whether or not the product is made with whole grains.

Also, some products that are 100% whole wheat but do not appear to be a good source of fiber, because the serving size is small. The bread label below is an example of this. The first ingredient is “stone ground whole wheat flour” with no refined flours listed, but it still has only 2g of fiber and 9% DV. But of course, that still contributes to your fiber intake for the day, and if you made yourself a sandwich with two slices of bread, that would provide 18% of the DV.



Figure 4.28. Example of 100% whole wheat bread with Nutrition Facts and ingredient list.

YouTube Video

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

View this YouTube Video online

VIDEO: "Label Reading and Whole Grains" by Tamberly Powell, YouTube (September 24, 2018), 7:46 minutes.

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5.7: Sugar — Food Sources, Health Implications, Intakes, and Label-Reading to Identify Sugar

Most of us enjoy the taste of sweetness, but you've also probably heard that you shouldn't eat too much sugar. Maybe you've even heard that sugar is *toxic*. The truth about sugar is more complex. It's true that most Americans eat more added sugar than recommended and would benefit from cutting back. It's also true that added sugars are hidden in many foods, and it can take savvy label-reading to find them. But let's also remember the big picture when we think about sugar. Some sugar is naturally-occurring in whole foods, packaged with other valuable nutrients. There's also room in the diet for some added sugar, and it can be valuable for making nutrient-dense foods more palatable or just for the pleasure of enjoying a treat. Let's look closer at the role of sugar in the diet.

Food Sources of Naturally-Occurring and Added Sugars

As we've already discussed, sugars are naturally found in fruits, veggies, and dairy. These are nutrient dense foods that come packaged with other essential nutrients too.



Figure 4.29. Examples of food that contain naturally occuring sugars: fruit, vegetables, and dairy.

Fresh fruits and veggies contain ***naturally-occurring sugars*** like glucose, fructose, and sucrose, but also come packaged with fiber, potassium, and Vitamin C. Dairy foods like unsweetened yogurt, milk, and cheese contain naturally-occurring lactose but also come packaged with calcium, potassium, phosphorus, and riboflavin.

Another food that contains natural sugar in the form of maltose is sprouted grain bread. In the example below, the only ingredients are sprouted organic rye kernels and water, yet there are 7g of sugar per slice. This sugar must be naturally-occuring maltose, and as you can imagine, it comes packaged with nutrients like fiber, protein, and iron.

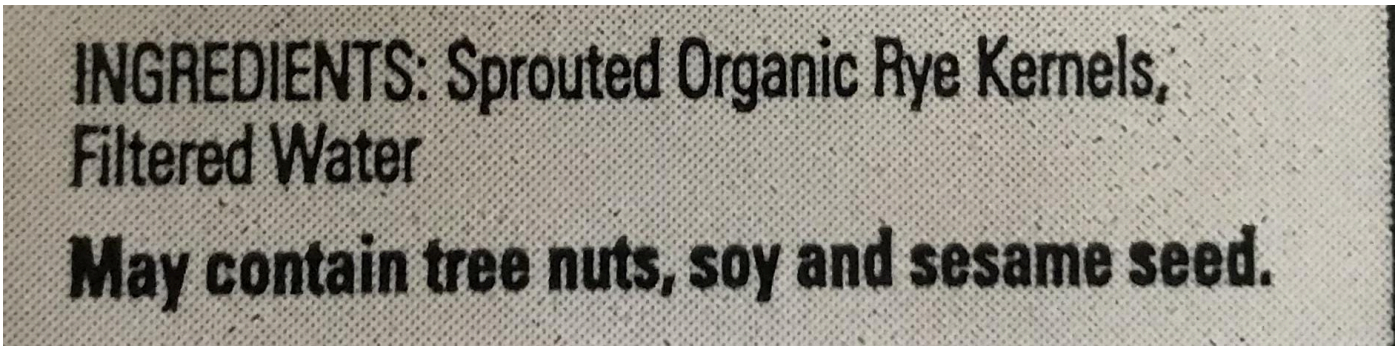


Figure 4.30. An example of a sprouted wheat bread that contains naturally occuring maltose from sprouted rye kernels.

In contrast, ***added sugars*** are concentrated sweeteners that are added as ingredients to foods to make them sweeter. They add calories to a food but contribute little to no essential nutrients, so they decrease the nutrient density of foods. Among the most common sources of added sugar are table sugar (sucrose) and high fructose corn syrup, but they come in many different forms

with different names. For example, honey, maple syrup, agave nectar, and brown rice syrup may all sound more wholesome and natural, but they're still added sugars, because they are concentrated sweeteners that contribute little to no other nutrients. Other names for added sugar you might not recognize as sweeteners at all, like barley malt or treacle. Here's a list of 61 different names for added sugars:



Figure 4.31. Names of sugar commonly added to food.

We find added sugars in some expected places, like cookies, ice cream, and soda, but there can also be a surprising amount of added sugar in yogurt, breakfast cereals, energy bars, and plant-based milk alternatives, like soy milk. We also find added sugars hiding in unexpected places, like ketchup, salad dressings, bread, and pasta sauce. In fact, nearly 75% of packaged products in the U.S. food supply are now sweetened.

In general, most people don't need to worry much about how much naturally-occurring sugar they consume. This goes back to the fact that naturally-occurring sugars are packaged with other nutrients. For example, a large apple contains about 23 grams of sugar, more than half of it in the form of fructose.[1] However, it also has more than 5 grams of fiber, plus a significant amount of vitamin C and potassium. The fiber slows down the digestion and absorption of the sugar into your bloodstream, giving your body more time to metabolize it and giving you a greater feeling of fullness.

A single can of soda, on the other hand, contains about 33 grams of sugar.[1] It's in a similar chemical form as the sugar in the apple—a mix of fructose and glucose—but it's not accompanied by any fiber to slow down digestion. Therefore, it's rapidly absorbed into your bloodstream, and your body has to quickly metabolize the fructose to glucose and increase insulin secretion to process the spike in sugar. Plus, although the soda contains 150 calories and the apple has just 116, the apple is probably going to leave you feeling more satisfied and less hungry compared with the soda.

For all of these reasons, it's the added sugars that we worry about, not the naturally-occurring ones. That said, there is room for some added sugar in a balanced diet, and you can use it to make nutrient-dense food tastier. For example, you can drizzle honey into plain yogurt or sprinkle some brown sugar on roasted winter squash. You get far more nutritional "bang for your buck" using added sugars in this way than consuming them in something like a soda. (And of course, there's also room in a balanced diet for occasional treats!)

How much added sugar are we eating?

On average, Americans consume 22 to 30 teaspoons of added sugar daily, up to 17% of calories, well in excess of the recommendation to **limit added sugar intake to 10% of calories or less**. This is shown in the image below from the Dietary Guidelines.

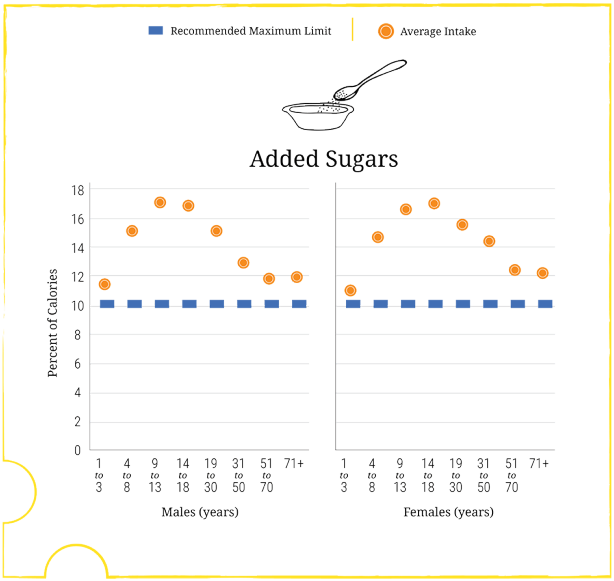


Figure 4.32. Average intakes of a *dded sugars as a percent of calories per day by age-sex group, in comparison to the Dietary Guidelines' maximum limit of less than 10 percent of calories.*

Where are all of these added sugars coming from? Nearly half of them come from soda, juices, and other sugary drinks, as illustrated below. Therefore, the Dietary Guidelines recommend that people drink more water and less sugary drinks.

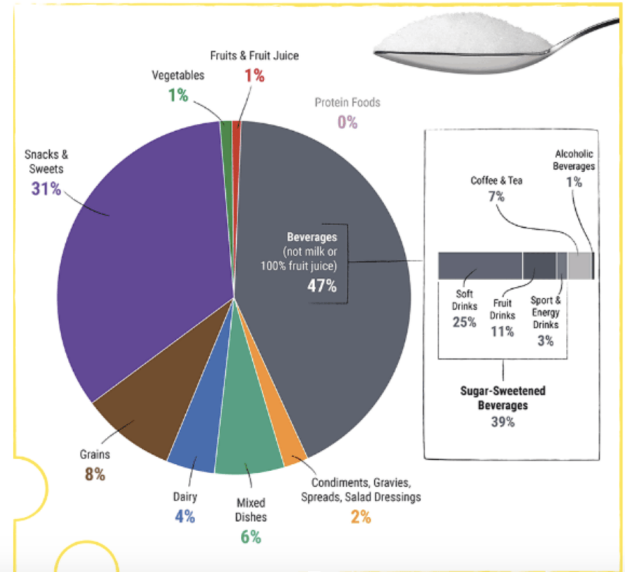


Figure 4.33. Food category sources of added sugars in the U.S. population ages 2 years and older.

On the Nutrition Facts panel, sugar is expressed in grams, but most of us don't think in grams. Therefore, it can be helpful to convert gram amounts to teaspoons, which are easier to visualize. Use the conversions shown in the graphic below to make these calculations.

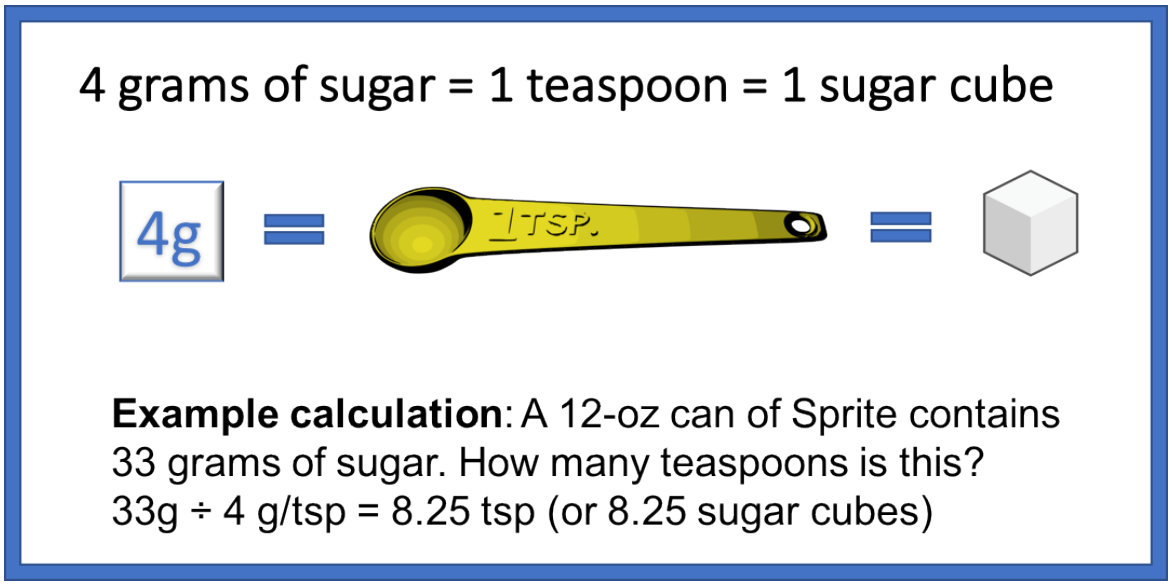


Figure 4.34. One teaspoon is equal to 4g of sugar or a sugar cube.

The sugar in soda adds up fast, especially with our super size portions. For example, a 64 oz. soda has 186 grams of sugar, or about 46 teaspoons. (186g divided by 4g/tsp = 46 tsp.)



Figure 4.35. Forty six sugar cubes stacked next to a big gulp to illustrate the 46 teaspoons of sugar that the soda contains.

It can be eye-opening to track your added sugar intake for a few days, and this may give you an idea of sources of added sugar that you can live without and replace with something else. However, tracking added sugar intake is difficult to do since it can be hard to differentiate added and naturally-occurring sugars on food labels. In the big picture, it's most important to focus on eating WHOLE foods that are minimally processed and to consume added sugars in moderation.

Benefits of Eating Less Added Sugar

Research shows that adopting an eating pattern that is relatively low in added sugars has many benefits, including a lower risk of:

- Cardiovascular disease
- Obesity
- Type 2 diabetes
- Some cancers

- Dental cavities

Why does too much added sugar cause health problems? The reasons are complex, and this is an ongoing area of research and controversy. One possible explanation is that a diet high in added sugar means the pancreas has to work hard to make enough insulin, and over time, it can begin to fail and the body's cells start to become insulin resistant. The liver also has to work hard to metabolize fructose, and too much fructose increases fat synthesis, which can raise blood lipid and cholesterol levels, increasing risk of heart disease.

Both dietary sucrose and starch are associated with tooth decay. Bacteria living in the mouth can utilize the carbohydrates passing through the oral cavity for their own benefit. Those bacteria happily metabolize carbohydrates, especially sucrose, but also starchy foods, which stick to teeth and linger there. Acid is formed in the process, and this can dissolve your tooth enamel, eventually causing cavities, also known as dental caries. Reducing sugar intake, limiting between-meal snacks, and brushing after meals to remove lingering carbohydrates can help reduce the risk of dental caries. The use of fluoride and regular dental care also help.

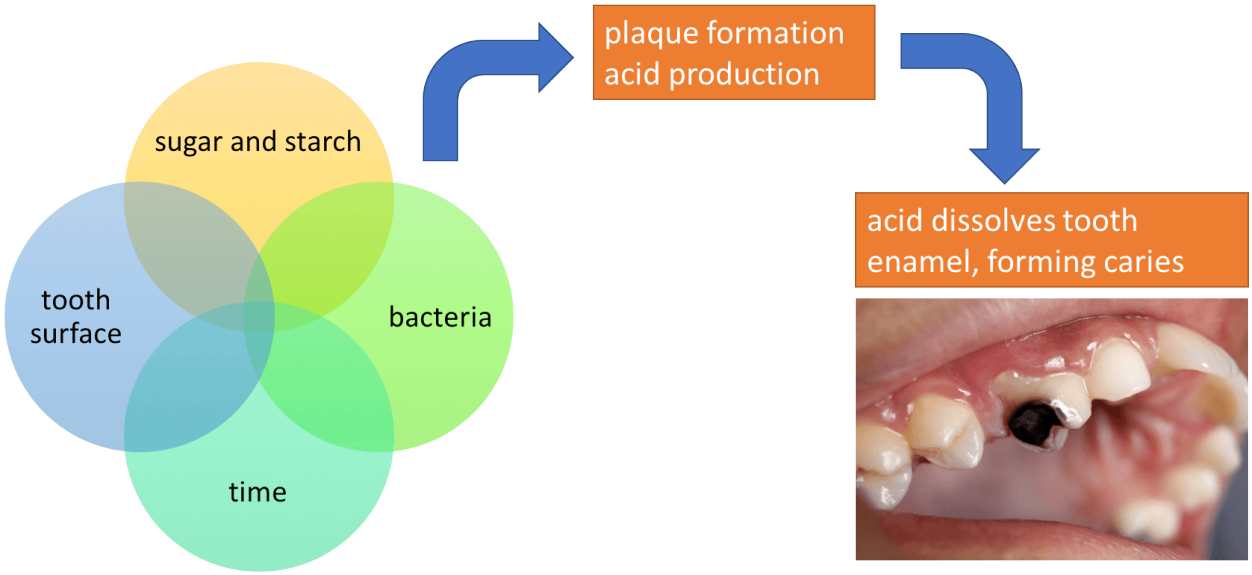


Fig. 4.36. Dental caries are formed because of a combination of factors: the presence of oral bacteria; a supply of sugar and/or starch for them to eat; tooth surface where they can form colonies, or plaque; and time.

Are Some Added Sugars Better Than Others?

Students often ask which sugar is healthiest: high fructose corn syrup, honey, agave syrup, or sugar? In general, as far as the body is concerned, sugar is sugar. These are all concentrated sweeteners that contain calories with very few/no other nutrients, so all should be used only in moderation.

High fructose corn syrup (HFCS) has gotten a lot of attention in the last several decades and has been blamed for the obesity epidemic and many other poor health outcomes. This is in part because it's widely used to sweeten soda and so has become a large part of the American diet. It's true that fructose is more work for the body to process, because it has to be converted to glucose. Here's what the website Sugar Science, written by researchers and scientists from the University of California, San Francisco, has to say about the difference between table sugar and high fructose corn syrup:

> *"Table sugar (sucrose), derived from sugar cane and beets, is made up of equal portions of two types of sugars. It's half (50%) glucose and half (50%) fructose. High-fructose corn syrup (HFCS) is derived from corn syrups that have undergone enzymatic processing to convert some of their glucose into fructose to produce a desired sweetness. HFCS comes in different formulations, depending on the manufacturer. More common formulations contain 42% fructose or 55% percent, but some contain as much as 90%. Why should we care? First, because there is significant evidence that fructose is processed differently in the body than other sugars and can be toxic to the liver, just like alcohol. Second, because as a nation, we have been consuming more of our sugars in HFCS over time."*

But focusing too much attention on fructose as the problem may risk missing the forest for the trees. Here's what Dr. Luc Tappy, a fructose researcher at University of Lausanne, had to say about the issue in an article on Vox.com:

> *"Given the substantial consumption of fructose in our diet, mainly from sweetened beverages, sweet snacks, and cereal products with added sugar, and the fact that fructose is an entirely dispensable nutrient, it appears sound to limit consumption of sugar as part of any weight loss program and in individuals at high risk of developing metabolic diseases. There is no evidence, however, that fructose is the sole, or even the main factor in the development of these diseases, nor that it is deleterious to everybody, and public health initiatives should therefore broadly focus on the promotion of healthy lifestyles generally, with restriction of both sugar and saturated fat intakes, and consumption of whole grains, fresh fruits and vegetables rather than focusing exclusively on reduction of sugar intake."*

YouTube Video

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

View this YouTube Video online

Video: "What's The Difference Between Sugar and High Fructose Corn Syrup?" by Reactions, YouTube (March 23, 2015), 2:41 minutes.

Are sweeteners such as honey, maple syrup, and molasses any better than more refined and processed sweeteners? Maybe. These sweeteners do contain minerals and antioxidants, so they may offer a slight edge in terms of nutrition. However, keep in mind that minerals and antioxidants are abundant in whole foods such as whole grains, vegetables, and fruits, and these obviously offer many other benefits. These sweeteners are still considered sources of added sugar and should be used in moderation. That said, each of them offers different delicious flavors, and honey has the added benefit that it can be purchased locally, so there are good reasons to turn towards these products when you want to add some sweetness to your food.

Label-Reading to Identify Sugar

If you're trying to figure out if a food is high in sugar, there are two places you should look on the label. First, check the Nutrition Facts panel to see how many grams of sugar are in one serving. However, labels are not yet required to list added sugars separately (though some are doing this already), so be aware that the "Sugars" on the label includes both added and naturally-occurring sugars. That's why you also need to check the ingredients list to look for any sources of added sugar (may be listed as any of the 61 different names in the graphic high on this page).

Let's take a look at some labels to practice identifying natural and added sugars in foods.

Below are labels from an 8-ounce serving of **Plain** Yogurt. There are 12 grams of sugar listed on the label. Is this sugar naturally-occurring or added?

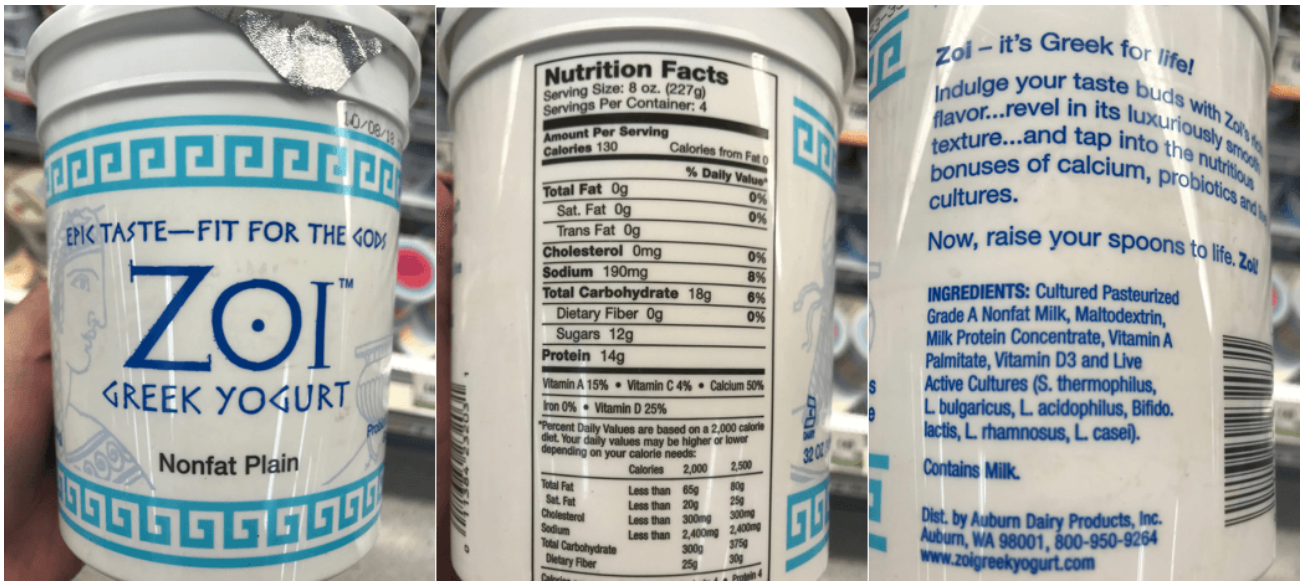


Figure 4.37. Plain yogurt with Nutrition Facts and ingredient list.

To answer this question, look at the ingredients. They include nonfat milk, maltodextrin (a food additive that is a polysaccharide), milk protein concentrate, vitamins and bacteria. There are no sources of added sugar in the ingredient list, so the 12 grams of sugar shown on the Nutrition Facts are from naturally-occurring lactose in the milk.

Next, look at the label below for an 8-ounce serving of sweetened strawberry yogurt. There are 35 grams of sugar listed on the label. Is this sugar naturally-occurring or added?

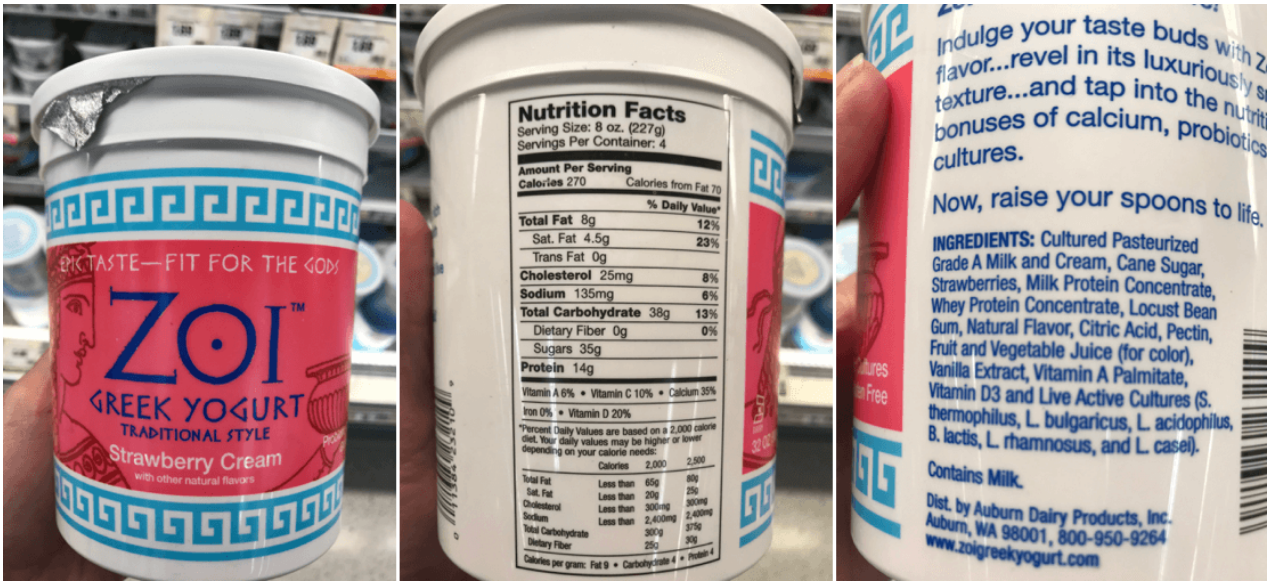


Figure 4.38. Strawberry yogurt with Nutrition Facts and ingredient list.

To answer this question, we again have to look at the ingredients list. Like the plain yogurt, the first ingredient is milk, but this strawberry yogurt also contains cane sugar and strawberries. Based on these ingredients, the 35 grams of sugar are a combination of both added and naturally-occurring sugars. The added sugar comes from cane sugar, and the naturally-occurring sugar is from the lactose from the milk and the glucose, fructose and sucrose in the strawberries.

How much sugar is naturally-occurring and how much is added? To answer this, you have to do some detective work and compare the plain and sweetened yogurts. The strawberry yogurt has 23 more grams of sugar than the plain yogurt, but some of this is naturally-occurring from the strawberries, so we can't calculate this precisely. I bet a lot of this 23 grams of sugar is added since cane sugar is the second ingredient listed (maybe as much as 5 teaspoons). Once all food labels are updated to include added sugars, it will be easy to identify them on the Nutrition Facts.

Not all yogurts are created equal, and many of them have less ingredients and less sugar than the example given above with the Greek yogurt. One example is siggi's Icelandic style skyr. As you can see in the images below, the ingredients are simple, and there is a lot less sugar than traditional yogurts.



Figure 4.39. Siggi's plain yogurt and Nutrition Facts.

In this Plain yogurt, a 5.3 oz serving has 16g of protein, and only 4g of naturally occurring lactose coming from milk. The only ingredients are milk and live active cultures.



Figure 4.40. Siggi's strawberry yogurt and Nutrition Facts.

In the strawberry yogurt, a 5.3 oz serving has 11g of sugar. This would be a combination of naturally occurring sugars coming from the milk and strawberries, and added sugar coming from the cane sugar. The strawberry yogurt has 7g more sugar, than the plain yogurt, but some of this is coming from the strawberries. How much of this 7g of sugar is added? It is hard to know, but with cane sugar being one of the last ingredients, it may have only 1 teaspoon of added sugar (about 4g). This is a big difference from the strawberry Greek yogurt above.

New Nutrition Facts Labels and Added Sugars

The images of the Nutrition Facts labels on the yogurts discussed above are the older versions of the Nutrition Facts labels, which did not distinguish between naturally occurring and added sugars. The new Nutrition Facts label, updated by the U.S. Food and Drug Administration (FDA) in 2016 and now required on most packaged foods, includes a separate line under "Total Sugars" that lists the amount of "Added Sugars." This change helps consumers identify how much sugar has been added during processing or preparation, as opposed to sugars naturally present in foods like fruit or milk.

Choosing foods with zero or minimal added sugars is ideal for maximizing nutrient density keeping added sugars to no more than 10% of total energy intake. By requiring added sugars to be clearly identified, the FDA aims not only to inform consumers but also to encourage food manufacturers to reformulate products and reduce added sugars — much like what occurred after trans fat labeling was mandated in 2006, which led many companies to eliminate or significantly reduce trans fatty acids in their products.

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5.8: Sugar Substitutes

You should now understand the problems with consuming too much added sugar, but what if you've sworn off regular soda and switched to diet versions? What if you're choosing "sugar-free" products, sweetened not with sugar but with sugar substitutes like aspartame, saccharin, or stevia? Are these a better choice?



Figure 4.41. Examples of products containing high-intensity sweeteners: diet soda, sugar-free chocolate, and bulk containers of Splenda and stevia extract.

Diet sodas are the biggest source of sugar substitutes in the American diet, but these ingredients are found in a range of foods, including ice cream, yogurt, cereals, iced tea, energy drinks, candy, cookies, granola bars, salad dressings, frozen dinners, and energy bars.[1] Products containing sugar substitutes are often labeled as sugar-free or "lite," but some don't have any front-of-package labeling with this information, and you may not even realize that you're consuming them. With more consumers watching their sugar intake, the use of sugar substitutes is growing, and the food industry is working hard to market them as a healthier choice. We can expect to see them in more and more products, so it's important to understand what these substances are and what they may mean for our health.

What Are Sugar Substitutes?

You may find ***sugar substitutes*** called lots of different things, including artificial, non-nutritive, high-intensity, or low-calorie sweeteners. Regardless of the name, these are substances that have a sweet taste but few or no calories.[2] In fact, they are much sweeter than sucrose, so a tiny amount can add a lot of sweetness to food. (Sweetener packets like Splenda and Equal contain a small amount of sweetener and a lot of filler ingredients.)

Sweetener	Brand Names	Sweetness *(relative to sucrose)*
Acesulfame Potassium (Ace-K)	Sweet One® Sunett®	200x
Advantame		20,000x

Aspartame	Nutrasweet® Equal® Sugar Twin®	200x
Neotame	Newtame®	7,000-13,000
Saccharin	Sweet'N Low® Sweet and Low® Sweet Twin® Necta Sweet®	200-700x
Sucralose	Splenda®	600x
Luo Han Guo or monk fruit extracts	Nectresse® Monk Fruit in the Raw® PureLo®	100-250 x
Stevia	Truvia® PureVia® Enliten®	200-400 x

Table 4.5. Sugar substitutes approved by the FDA for use in the United States with their brand names and sweetness relative to sucrose.[3]

Unlike regular sugar, the sweeteners listed in the table above are not associated with dental caries, and they generally don't raise blood glucose.[1]

Sugar alcohols are another type of sugar substitute. They include sorbitol, mannitol, lactitol, erythritol, and xylitol. They are chemically similar to monosaccharides but different enough that they aren't processed in the body to the same extent. However, they are at least partially metabolized and contain about 2 kcal/gram (compared with 4 kcal/gram for sucrose). (An exception is erythritol, which contains just 0.2 kcal/g.) Unlike the sweeteners listed in the table above, they are not "high-intensity" but instead are generally less sweet than sucrose. Because they are not fully digested, consuming large amounts of them can cause bloating, gas, and diarrhea.[1]

Sugar alcohols are often used in sugar-free chewing gums and breath mints and can carry a health claim that they don't promote tooth decay, because mouth bacteria can't easily metabolize them. Xylitol in particular has been studied for its ability to decrease the incidence of tooth decay. However, these studies generally use large doses. For example, a person might have to chew xylitol gum five times per day to see a benefit. The American Academy of Pediatric Dentistry supports the use of xylitol but says the evidence for benefit is not clear and that amounts required may not be practical in real life.[4]

Can Sugar Substitutes Help With Weight Loss?

When people choose diet soda or a sugar-free dessert, they're probably assuming that it's a healthier choice and perhaps that it could help them lose weight. However, studies show this isn't necessarily the case.

In the short-term, if someone who drinks a lot of sugar-sweetened beverages switches to diet versions, studies show that this can result in weight loss. That makes sense, because you're removing a lot of empty calories from the diet.[5]

However, in the long-term, studies show there isn't a clear benefit to consuming sugar substitutes. A recent systematic review and meta-analysis combined the results of studies that lasted at least 6 months.[6] Among the randomized controlled trials, they found no difference in body mass index (BMI—a measure of the ratio of body weight to height) between people who consumed sugar and those who consumed sugar substitutes. Observational studies that tracked large groups over years found that people who consumed sugar substitutes tended to have a higher BMI, greater weight and waist circumference, and a higher incidence of obesity, hypertension, metabolic syndrome, type 2 diabetes, and cardiovascular events.[7] Because these are observational studies, we can't conclude that the sugar substitutes *cause* these health outcomes, but we can conclude that their use is not associated with better health.

When it comes to weight management, the goal is to adopt eating habits that support a **sustainable** healthy body weight. Sugar substitutes might help in the short-term with decreasing calorie intake and perhaps gradually moving away from sweetened beverages, but better long-term goals for health would be to shift to water and other unsweetened beverages. If you're looking for a way to sweeten your oatmeal or yogurt, you might try adding fresh fruit rather than sugar or an artificial sweetener packet. (Or go ahead and add a bit of brown sugar or a drizzle of honey, keeping in mind the overall goal of moderation.)

Are High-Intensity Sweeteners Safe?

Over the years, there have been a number of concerns about non-nutritive sweeteners. For example, in the 1970s, studies showed that saccharin was linked to bladder cancer in lab rats, so it was labeled as a potential carcinogen, although its use as a sweetener continued. In 2000, after many studies showed no link between cancer and saccharin, the warning labels were no longer required. Some studies have also raised concerns about a link between aspartame and sucralose and cancer, but the FDA has reviewed this evidence and concluded: "Based on the available scientific evidence, the agency has concluded that the high-intensity sweeteners approved by FDA are safe for the general population under certain conditions of use." The National Cancer Institute also says there is no clear evidence that high intensity sweeteners cause cancer.[8]



Figure 4.42. A "Saccharin Notice" sign warns consumers that a grocery store shelf contains products with saccharin, which has been shown to cause cancer in laboratory animals. Between 1977 and 2000, products containing saccharin had to include a cancer warning label. This requirement was removed after the U.S. Department of Health and Human Services determined it was not a concern in humans at doses typically consumed.

There are other emerging safety concerns about sugar substitutes, though. Small studies on both mice and humans show that consuming artificial sweeteners can change our gut bacteria and cause glucose intolerance.[9-11] Glucose intolerance means that blood glucose is abnormally elevated, showing that glucose metabolism is not working properly, and it is a precursor to the development of diabetes. Other researchers worry that having the taste of sweetness signaled to the brain without accompanying calories could derail our normal pathways for sensing hunger and satiety and for regulating glucose metabolism.[12] This research is alarming but still preliminary. However, it is an active area of study, and we can expect more information to emerge in the years to come.

Are Natural Sweeteners Better Than Artificial Ones?

Sweeteners made from the stevia plant and from monk fruit extracts are both derived from plants and so are considered more natural than the other choices. However, it's important to not confuse natural with safe. Remember that many things in nature are dangerous, even deadly. (Consider cyanide, poisonous mushrooms, and botulinum toxin, for example.) Stevia sweeteners, which are growing in popularity and are often marketed as a more natural alternative, are made through a highly industrial extraction process, and some are produced by genetically-modified yeast. None of that makes them inherently less safe, but it does highlight that they aren't exactly natural.



Figure 4.43. A box of Sweetleaf sweetener, marketed as "Natural Stevia Sweetener."

What's important is how well these products are tested and studied for their safety. The Center for Science in the Public Interest, a consumer advocacy nonprofit organization, has criticized the FDA for not requiring more testing of stevia and monk fruit extracts, although they recommend stevia as one of the safer options for sugar substitutes based on existing data. However, recent research has shown that, like artificial sweeteners, stevia also affects the growth of gut bacteria.

What's the Bottom Line?

Sugar substitutes can add sweetness to a food without the calories, and they aren't associated with tooth decay. Despite concerns over the years, they probably don't cause cancer. However, they may not help with weight loss or maintenance in the long-term, and recent research shows that they may alter the gut microbiota and metabolic health.

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CHAPTER 6: LIPIDS

Learning Objectives

After completing this unit, you should be able to:

1. Describe and appreciate the important functions of fats in our bodies and our diets.
2. Identify the three major types of lipids, and describe their structure, food sources, and functions.
3. Describe the structure, food sources, and health impacts of saturated, polyunsaturated, monounsaturated, and trans fatty acids.
4. Identify and define the essential fatty acids and their major functions.
5. Describe the processes of digestion and absorption of fats in the body.
6. Describe how lipids are transported around the body and utilized by cells, and what blood cholesterol values indicate about a person's health.
7. Explain the dietary recommendations for fats and the evidence for how dietary fats impact heart health.

6.1: Introduction to Lipids

6.2: The Functions of Fats

6.3: Lipid Types and Structures

6.4: Fatty Acid Types and Food Sources

6.5: Digestion and Absorption of Lipids

6.6: Lipid Transport, Storage, and Utilization

6.7: Lipid Recommendations and Heart Health

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6.1: Introduction to Lipids

When you think of foods important to the Pacific Northwest, salmon may first come to mind. But to many indigenous people who have long made their home along the Pacific coast, a smaller, humbler fish is considered even more vital: the eulachon smelt.

Traditionally, one of the first signs of spring in the region was the migration of the eulachon smelt into the region's rivers. These thin, blue and silver fish spend most of their lives in the cold Pacific Ocean, but when it's time for them to lay their eggs in early spring, they swim up into the rivers of Oregon, Washington, Canada, and Alaska to sow the seeds of their next generation.

For indigenous people living in this region, who historically subsisted through long winters on stored and preserved foods, the arrival of the eulachon smelt would have been a welcome infusion of calories and flavor. Legends describe the small oily fish saving entire villages from starvation; it's also known as "*halimotkw*," translated as "savior fish" or "salvation fish."



Figure 6.1.1: Fresh-caught eulachon smelt from the Kuskokwim River, Alaska, 2008. ("Kuskokwim Smelt" by Andrea Pokrzywinski is licensed under CC BY 2.0)

Beyond the timing of its late winter arrival, what makes the eulachon so valuable is its high lipid content. It's so oily that dried eulachon will ignite and burn like a candle, and nutritionally, it's a dense source of calories. (Remember: Fat contains 9 kilocalories per gram compared to just 4 for carbohydrate and protein.) It's also a good source of fat-soluble vitamins, especially vitamin A, and high in omega-3 fatty acids. William Clark (of the Lewis and Clark expedition), after tasting eulachon from the Columbia River in 1805, wrote: "They are so fat they require no additional sauce, and I think them superior to any fish I ever taste[d], even more delicate and luscious than the white fish of the lakes which have heretofore formed my standard of excellence among the fishes."

Clark may have been the first person of European descent to document the eulachon, but it had long been valued by indigenous people, including members of the Tsimshian, Tlingit, Haida, Nisga's, and Bella Coola tribes. The eulachon run was an annual community event, and people camped for several weeks at the mouths of rivers to net and process the fish. They smoked eulachon to preserve it, but even more importantly, they fermented it in large batches and then cooked it to extract its oils. Once cooled, the fat was solid at room temperature—similar to lard or butter—and could be used for fat and flavor in cooking for the year ahead. It was so valuable that it was traded hundreds of miles inland, forming the great "grease trials" of the Northwest.



Video 6.1.1: "Watch a Fish Transform From Animal to Candle," by National Geographic (July 10, 2015), 2 minutes.

These traditional uses of the eulachon continue on a smaller scale, but since the 1990s, the eulachon population has collapsed. Researchers say ts biggest threat is climate change, and eulachon have been classified as a threatened species under the Endangered Species Act since 2010.

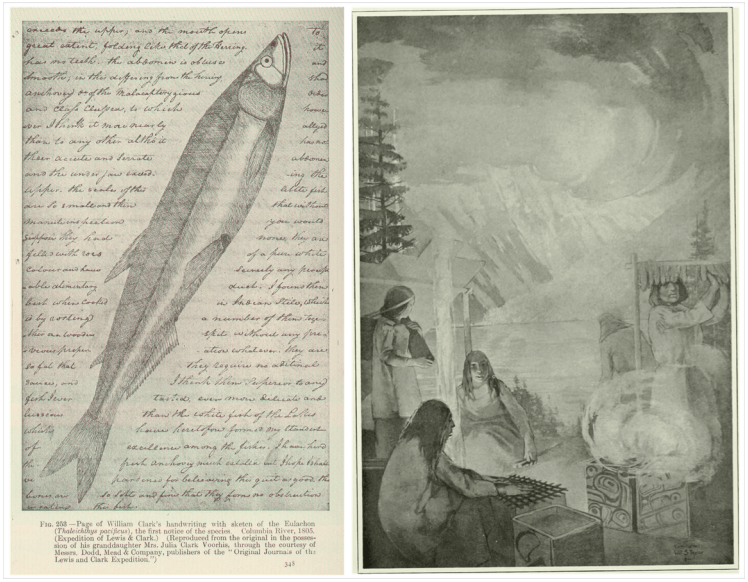


Figure 6.1.3: (left): A page from William Clark's journal of 1805, describing his observations of the euchalon smelt, including its "delicate and luscious" taste. ("Page of William Clark's handwriting with sketch of the Eulachon (Thaleichthys pacificus), the first notice of the species." by David Starr Jordan, Freshwater and Marine Image Bank, University of Washington is in the Public Domain) (right): Mural panel by Will S. Taylor, entitled "A Tsimshian Family Making Eulachon Butter," circa 1825, with this description: "The glow of the ember fire is on the girls face as she waits for stones to heat. In the box at the right, fish are being boiled by means of the heated stones: the oil thus removed from the fish forms "butter." The residue is being strained by the woman at the left." ("A TSIMSHIAN FAMILY MAKING EULACHON BUTTER" by Will S. Taylor, American Museum of Natural History Library is in the Public Domain)

In today's world—when we can obtain a day's worth of calories and more than enough fat with just a quick trip through a fast food drive-through—it's easy to forget the biological and cultural importance of lipids. But the historical significance of the eulachon remind us of how vital these molecules are to our survival.

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6.2: The Functions of Fats

Fats serve useful functions in both the body and the diet. In the body, fat functions as an important depot for energy storage, offers insulation and protection, and plays important roles in regulating and signaling. Large amounts of dietary fat are not required to meet these functions, because most fat molecules can be synthesized by the body from other organic molecules like carbohydrate and protein (with the exception of two essential fatty acids). However, fat also plays unique roles in the diet, including increasing the absorption of fat-soluble vitamins and contributing to the flavor and satisfaction of food. Let's take a closer look at each of these functions of fats in the body and in the diet.

The Functions of Fats in the Body

Storing Energy

The excess energy from the food we eat is incorporated into adipose tissue, or fatty tissue. Most of the energy required by the human body is provided by carbohydrates and lipids. As discussed in the Carbohydrates unit, glucose is stored in the body as glycogen. While glycogen provides a ready source of energy, it is quite bulky with heavy water content, so the body cannot store much of it for long. Fats, on the other hand, can serve as a larger and more long-term energy reserve. Fats pack together tightly without water and store far greater amounts of energy in a reduced space. A fat gram is densely concentrated with energy, containing more than double the amount of energy as a gram of carbohydrate.

We draw on the energy stored in fat to help meet our basic energy needs when we're at rest and to fuel our muscles for movement throughout the day, from walking to class, playing with our kids, dancing through dinner prep, or powering through a shift at work. Historically, when humans relied on hunting and gathering wild foods or on the success of agricultural crops, having the ability to store energy as fat was vital to survival through lean times. Hunger remains a problem for people around the world, and being able to store energy when times are good can help them endure a period of food insecurity. In other cases, the energy stored in adipose tissue might allow a person to weather a long illness.

Unlike other body cells that can store fat in limited supplies, fat cells are specialized for fat storage and are able to expand almost indefinitely in size. An overabundance of adipose tissue can be detrimental to your health not only from mechanical stress on the body due to excess weight, but also from hormonal and metabolic changes. Obesity can increase the risk for many diseases, including type 2 diabetes, heart disease, stroke, kidney disease, and certain types of cancer. It can also interfere with reproduction, cognitive function, and mood. Thus, while some body fat is critical to our survival and good health, in large quantities it can be a deterrent to maintaining good health.

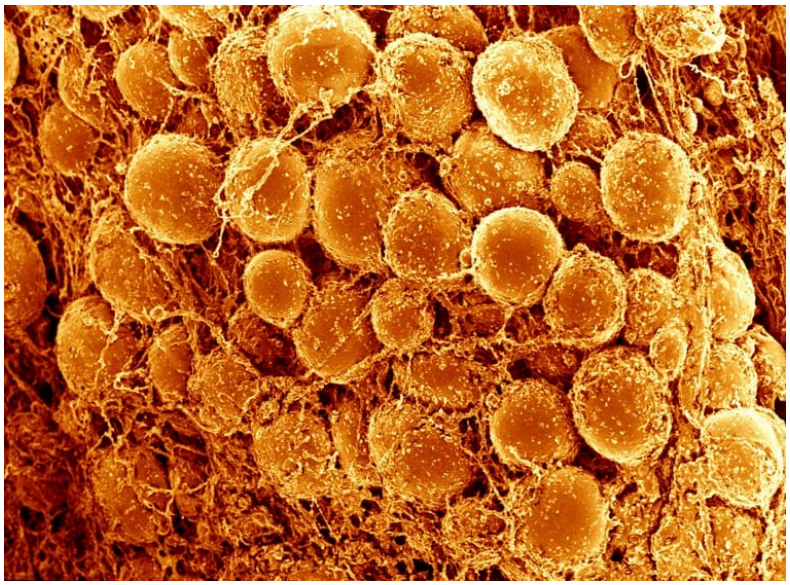


Figure 6.2.1: Scanning electron micrograph of adipose tissue, showing adipocytes. Computer-coloured orange. ("Adipose tissue, close-up showing adipocytes, SEM" by David Gregory & Debbie Marshall is licensed under CC BY 4.0)

Insulating and Protecting

The average body fat for a man is 18 to 24 percent and for a woman is 25 to 31 percent[1], but adipose tissue can comprise a much larger percentage of body weight depending on the degree of obesity of the individual. Some of this fat is stored within the abdominal cavity, called ***visceral fat,*** and some is stored just underneath the skin, called ***subcutaneous fat***. Visceral fat protects vital organs—such as the heart, kidneys, and liver. The blanket layer of subcutaneous fat insulates the body from extreme temperatures and helps keep the internal climate under control. It pads our hands and buttocks and prevents friction, as these areas frequently come in contact with hard surfaces. It also gives the body the extra padding required when engaging in physically demanding activities such as ice skating, horseback riding, or snowboarding.

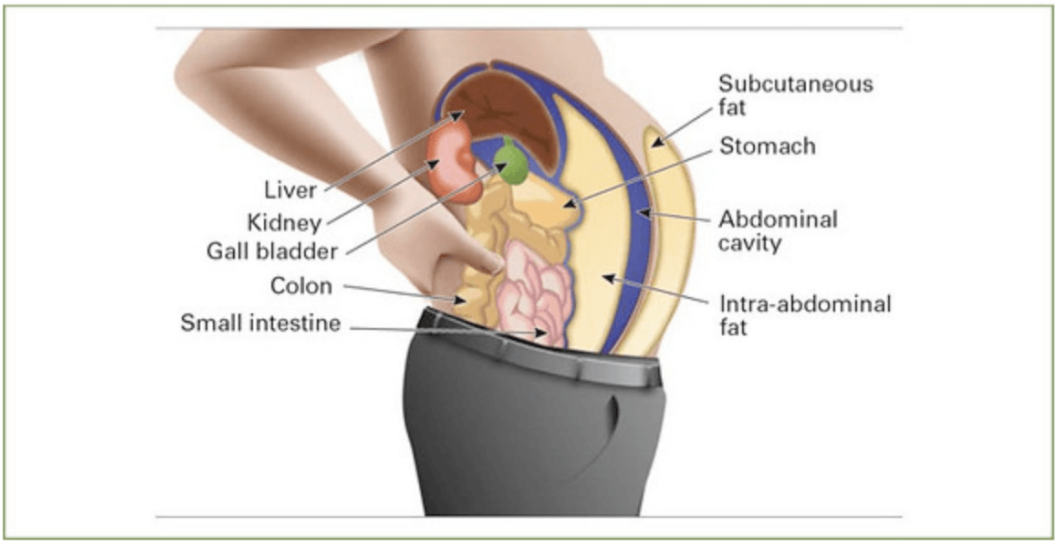


Figure 6.2.2: There are two types of fat stored as adipose tissue: subcutaneous fat and visceral fat. ("Pandemic of Lifestyle Disease" by Sandra Cohen-Rose and Colin Rose is licensed under CC-BY-2.0)

Regulating and Signaling

Fats help the body to produce and regulate hormones. For example, adipose tissue secretes the hormone leptin, which signals

the body's energy status and helps to regulate appetite. Fat is also required for reproductive health; a woman who lacks adequate amounts may stop menstruating and be unable to conceive until her body can store more energy as fat. 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. Lipids are especially focal to brain activity in structure and in function, helping to form nerve cell membranes, insulate neurons, and facilitate the signaling of electrical impulses throughout the brain.

The Function of Fats in our Diet

Aiding Absorption and Increasing Bioavailability

The dietary fats in the foods we eat aid in the transport of fat-soluble vitamins, carrying them through the digestive process and improving their intestinal absorption. This improved absorption is known as increased ***bioavailability***. Dietary fats can also increase the bioavailability of compounds known as ***phytochemicals*** — non-essential plant compounds considered beneficial to human health. Many phytochemicals are fat-soluble, such as lycopene found in tomatoes and beta-carotene found in carrots, so dietary fat improves the absorption of these molecules in the digestive tract.

In addition to improving bioavailability of fat-soluble vitamins, some of the best dietary sources of these vitamins are also foods that are high in fat. For example, good sources of vitamin E are nuts (including peanut butter and other nut butters), seeds, and plant oils such as those found in salad dressings, and it's difficult to consume enough vitamin E if you're eating a very low-fat diet. (Although fried foods are usually cooked in vegetable oils, vitamin E is destroyed by high heat, so you won't find a lot of vitamin E in french fries or onion rings. Your best bets are minimally-processed, whole foods.) Vegetable oils also provide some vitamin K, and fatty fish and eggs are good sources of vitamins A and D.

Contributing to the Smell, Taste, and Satiety of Foods

Fats satisfy ***appetite*** (the **desire** to eat) because they add flavor to foods. Fat contains dissolved compounds that contribute to mouth-watering aromas and flavors. Fat also adds texture, making baked foods moist and flakey, fried foods crispy, and adding creaminess to foods like ice cream and cream cheese. Consider fat-free cream cheese; when fat is removed from the cream, much of the flavor is also lost. As a result, it is grainy and flavorless—nothing like its full-fat counterpart—and many additives are used in an attempt to replace the lost flavor.

Fats satisfy ***hunger*** (the **need** to eat) because they're slower to be digested and absorbed than other macronutrients. Dietary fat thus contributes to ***satiety***—the feeling of being satisfied or full. When fatty foods are swallowed, the body responds by enabling the processes controlling digestion to slow the movement of food along the digestive tract, giving fats more time to be digested and absorbed and promoting an overall sense of fullness. Sometimes, before the feeling of fullness arrives, people overindulge in fat-rich foods, finding the delectable taste irresistible. Slowing down to appreciate the taste and texture of foods can give your body time to send signals of satiety to your brain, so you can eat enough to be satisfied without feeling overly full.

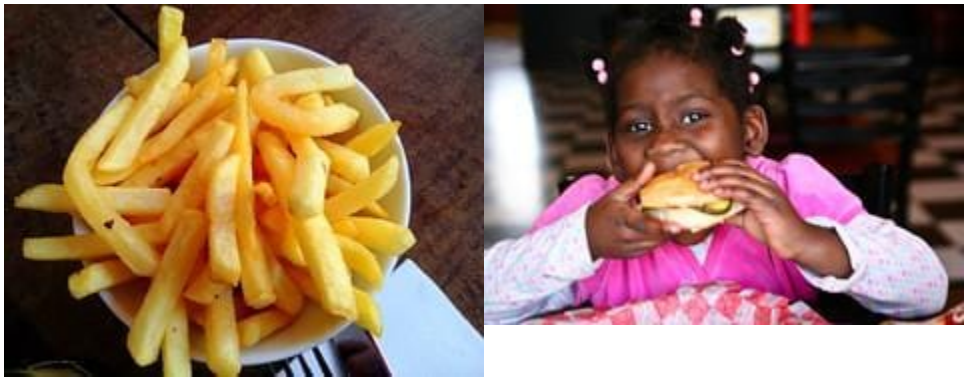


Figure 6.2.3: "French Fries in Paris" by Jim Larrison is licensed under CC BY 2.0 "Eating a Burger Jonny B'z Dog and More Lourdie Dinner March 24, 2016" by Steven Depolo is licensed under CC-BY-2.0

Providing Essential Fatty Acids

Most lipid molecules can be synthesized in the body from other organic molecules, so they don't specifically need to be provided in the diet. However, there are two that are considered essential and must be included in the diet: linoleic acid and alpha-linolenic acid. We'll discuss these two fatty acids in detail later in the unit.

Attributions

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References:

- ACE (2009) *What are the guidelines for percentage of body fat loss?* American Council on Exercise (ACE). Ask the Expert Blog. December 2, 2009.
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6.3: Lipid Types and Structures

Lipids are a family of organic compounds that are mostly insoluble in water, meaning they do not mix well with water. **There are three main types of lipids: triglycerides, phospholipids, and sterols.** On this page, we'll learn about the structures of these three types of lipids, as well as their functions in the body and where you can find them in foods.

Triglycerides

Triglycerides are the main form of lipids in the body and in foods. More than 95 percent of lipids in the diet are in the form of triglycerides, some having a visible presence and some hidden in foods. Concentrated fats (butter and vegetable oil, for example) and marbling of fat in meat are obviously visible. But fat can also be hidden in foods, as in baked goods, dairy products like milk and cheese, and fried foods. Naturally occurring triglycerides are found in many foods, including avocados, olives, corn, and nuts. We commonly call the triglycerides in our food "fats" and "oils." Fats are lipids that are solid at room temperature, whereas oils are liquid. The terms fats, oils, and triglycerides are often used interchangeably. In this unit, when we use the word fat, we are referring to triglycerides.

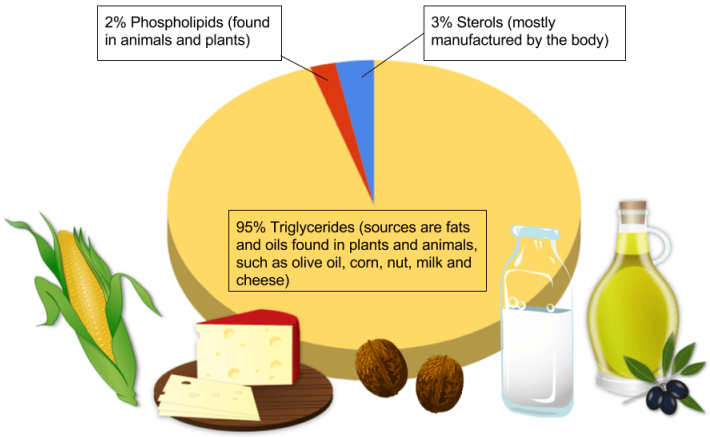


Figure 6.3.1: 95% of fats in the diet are in the form of triglycerides. Sterols (like cholesterol) make up about 3% of dietary fat intake and phospholipids make up roughly 2% of dietary fat intake. (Copyright; author via source)

The structure of a triglyceride is made up of glycerol and three fatty acids. ***Glycerol*** is the three-carbon backbone of triglycerides, while ***fatty acids*** are longer chains of carbon molecules attached to the glycerol backbone. The "glyceride" in the word "triglyceride" refers to this glycerol backbone, while the "tri" refers to the fact that there are three fatty acids attached. Fatty acids are called acids because they have an acid group (–COOH) on one end of a carbon chain. A monoglyceride contains glycerol with one fatty acid attached, and a diglyceride contains glycerol with two fatty acids attached.

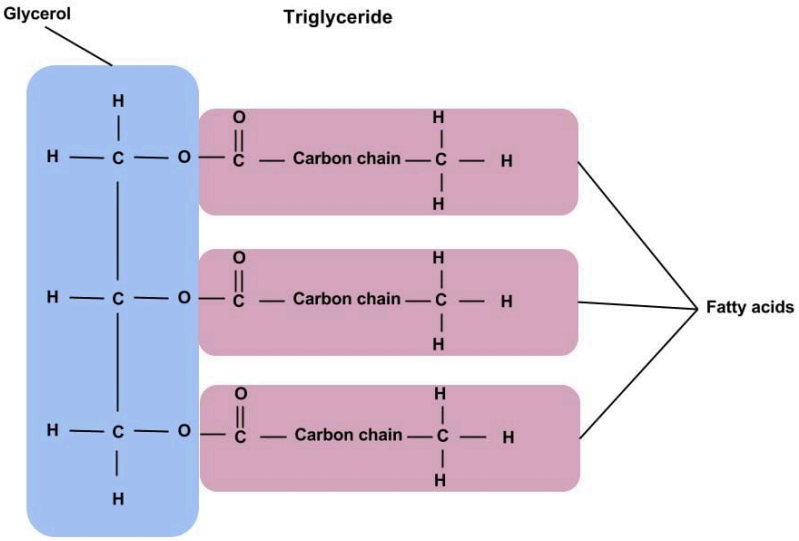


Figure 6.3.2: The chemical structure of a triglyceride, showing the glycerol backbone and three attached fatty acids. (Copyright; author via source)

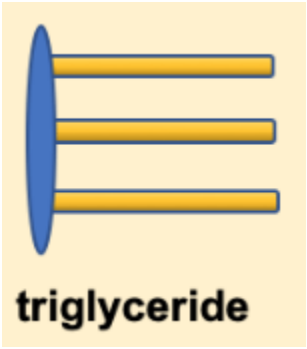


Figure 5.7. *The structure of a triglyceride is often depicted as a simplified drawing of the glycerol backbone and three fatty acids.*

There are different types of fatty acids, and triglycerides can contain a mixture of them. Fatty acids are classified by their carbon chain length and degree of saturation. Foods contain different proportions of fatty acid types, and this influences disease risks associated with dietary patterns. We will take a closer look at these differences, along with food sources, in the next section.

Phospholipids

Phospholipids are found in both plants and animals but make up only about 2 percent of dietary lipids. However, they play many important roles in the body and in foods. Phospholipids can also be synthesized by the body, so they don't have to be consumed in the diet.

Phospholipids are similar in structure to triglycerides (Figure 5.8). Like triglycerides, phospholipids have a glycerol backbone. But unlike triglycerides, phospholipids only have two fatty acid molecules attached to the glycerol backbone, while the third carbon of the glycerol backbone is bonded to a phosphate group—a chemical group that contains the mineral phosphorus.

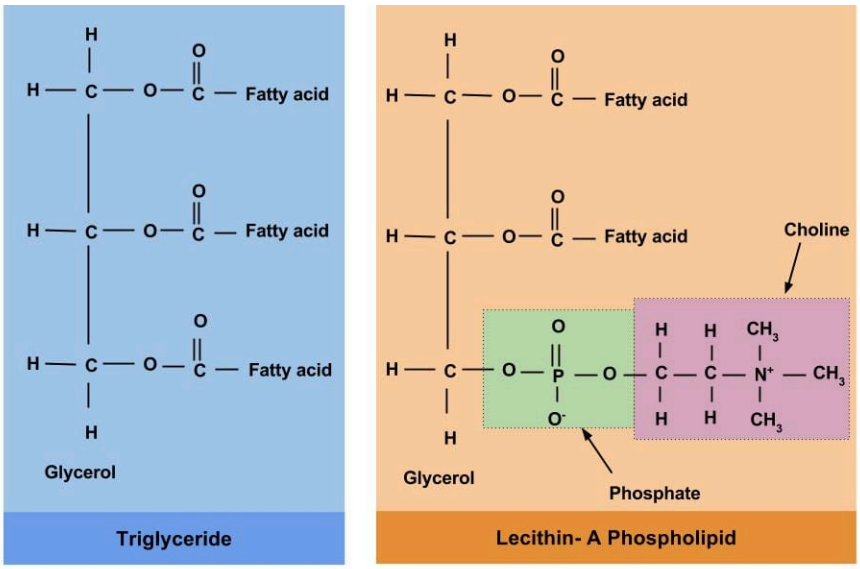


Figure 6.3.3: The structural difference between a triglyceride (on the left) and a phospholipid (on the right) is in the third carbon position, where the phospholipid contains a phosphate group instead of a fatty acid. (Copyright; author via source)

The unique structure of phospholipids makes them both fat- and water-soluble, or ***amphiphilic***. The fatty-acids are hydrophobic (dislike water), and the phosphate group and glycerol are hydrophilic (attracted to water).

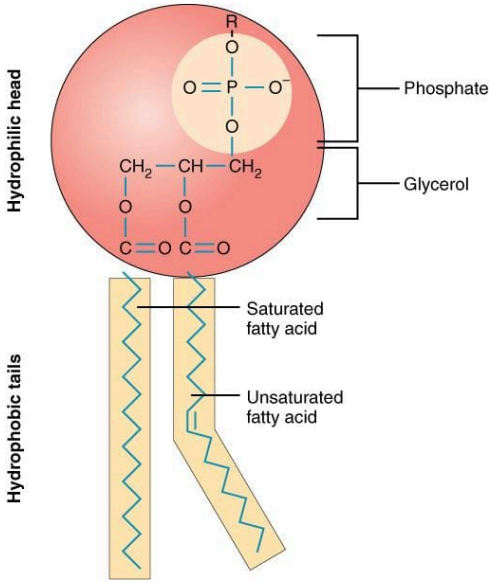


Figure 6.3.4: A phospholipid molecule consists of a polar phosphate “head,” which is hydrophilic, and a non-polar lipid “tail,” which is hydrophobic. (Copyright; author via source)

The amphiphilic nature of phospholipids makes them very useful for several functions in the body. Every cell in the body is encased in a membrane composed primarily of a double layer of phospholipids (also known as the phospholipid bilayer), which protects the inside of the cell from the outside environment while at the same time allowing for transport of fat and water through the membrane. Phospholipids also play a role in transporting fats in the blood, as we’ll learn later in this unit.

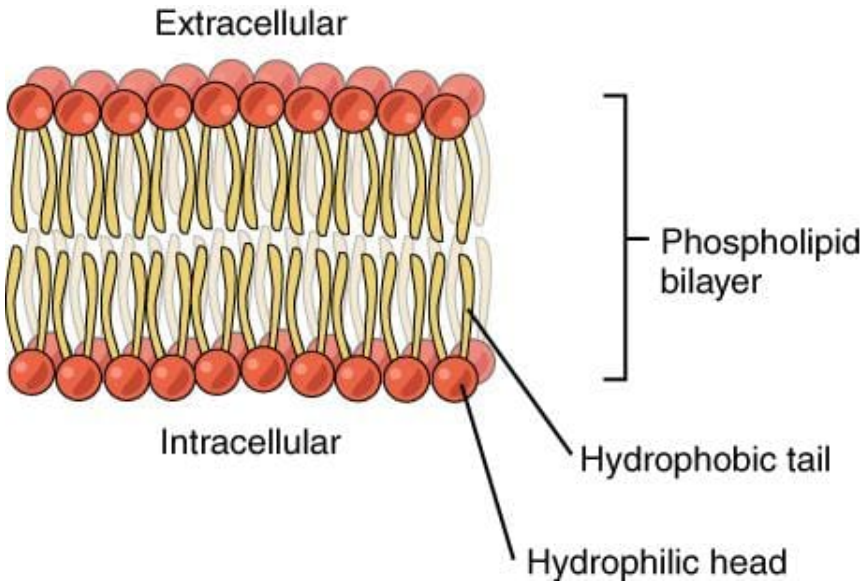


Figure 6.3.5: The phospholipid bilayer consists of two adjacent sheets of phospholipids, arranged tail to tail. The hydrophobic tails associate with one another, forming the interior of the membrane. The polar heads contact the fluid inside and outside of the cell.(Copyright; author via source)

Another important role of phospholipids is to act as ***emulsifiers***. Emulsions are mixtures of two liquids that do not normally mix (oil and water, for example). Without an emulsifier, the oil and water separate out into two layers. Because of their ability to mix with both water and fat, phospholipids are ideal emulsifiers that can keep oil and water mixed, dispersing tiny oil droplets throughout the water. Lecithin—a phospholipid found in egg yolk, soybean, and wheat germ—is often used as a food emulsifier. Emulsifiers also play an important role in making food appetizing; their inclusion in foods like sauces and creams makes for a smoother texture and prevents the oil and water ingredients from separating out. They also can extend shelf life.

Sterols

Sterols have a very different structure from triglycerides and phospholipids. Most sterols do not contain any fatty acids but rather are multi-ring structures, similar to chicken wire. 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 fatty plaques that narrow arteries and obstruct blood flow in ***atherosclerosis***. However, cholesterol also has many essential functions in the body. Like phospholipids, cholesterol is present in all body cells as it is an important substance in cell membrane structure. Cholesterol is also used in the body as a precursor in the synthesis of a number of important substances, including vitamin D, bile, and sex hormones such as progesterone, testosterone, and estrogens.

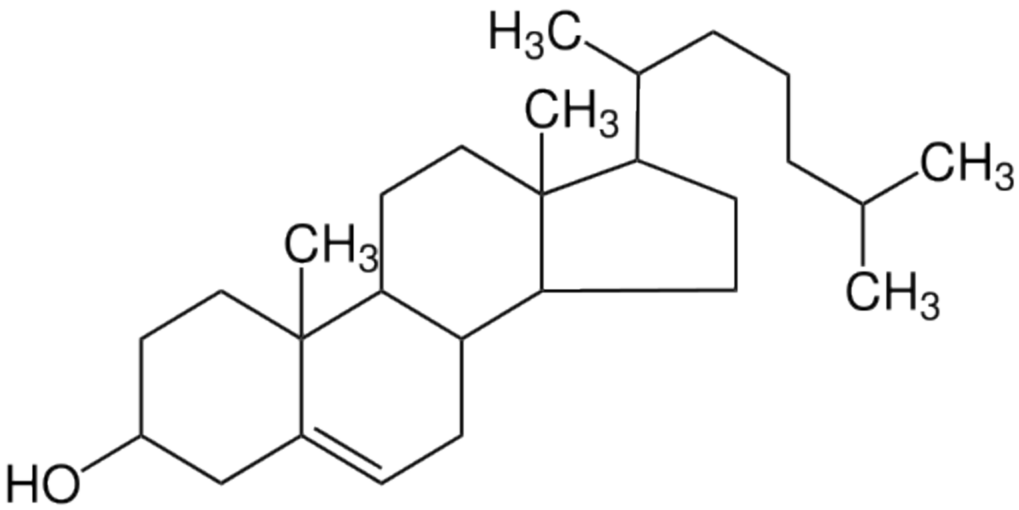


Figure 6.3.1: Cholesterol is made up of multiple carbon rings bonded together. ("Cholesterol Chemical Structure" by Wesalius is in the Public Domain)

Cholesterol is not an essential nutrient; it does not need to be consumed in the diet, because it is manufactured in the liver. **Only foods that come from animal sources contain cholesterol.** Cholesterol is found in foods like meat, poultry, fish, egg yolks, butter, and dairy products made from whole milk.

Plant foods do not contain cholesterol, but sterols found in plants resemble cholesterol in structure. Plant sterols inhibit cholesterol absorption in the human body, which can contribute to lower cholesterol levels, particularly lower LDL ("bad") cholesterol levels. Plant sterols occur naturally in vegetable oils, nuts, seeds, and whole grains. In addition, some foods like margarines and dressings are fortified with plant sterols.

Attributions

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6.4: Fatty Acid Types and Food Sources

On the previous page, we learned that triglycerides—the main form of fat in the body and in food—are made up of a glycerol backbone with three fatty acids attached. As mentioned, fatty acids can differ from one another in both carbon chain length and degree of saturation. These characteristics influence the resulting fat in many ways.

Chain Length of Fatty Acids

Fatty acids have different chain lengths, typically between four and 24 carbons, and most contain an even number of carbon atoms. When the carbon chain length is shorter, the melting point of the fatty acid becomes lower (such as fats found in dairy products) and the fatty acid becomes more liquid. Longer chain lengths tend to result in more solid fats, although melting point is also influenced by the degree of saturation.

Degrees of Saturation of Fatty Acids

Fatty acid chains are composed primarily of carbon and hydrogen atoms that are bonded to each other. The term “saturation” refers to whether the carbon atom in a fatty acid chain is filled (or “saturated”) to capacity with hydrogen atoms. In a ***saturated fatty acid,*** each carbon is bonded to two hydrogen atoms, with single bonds between the carbons.

Alternatively, fatty acids can have points where hydrogen atoms are missing, because there is a double bond between carbons (C=C). This is referred to as a point of unsaturation, because the carbon is only bonded to one hydrogen atom instead of two. ***Unsaturated fatty acids*** have one or more points of unsaturation, or double bonds between the carbons. A ***monounsaturated fatty acid*** is a fatty acid with one double bond, and a ***polyunsaturated fatty acid*** is a fatty acid with two or more double bonds.

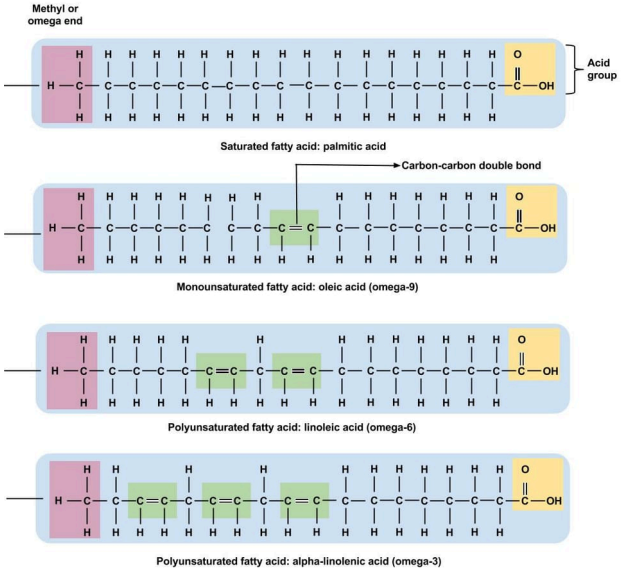


Figure 6.4.1: The structures of a saturated, monounsaturated, and polyunsaturated fat. Note the differences in points of unsaturation (C=C double bonds) on some of the fatty acids.

Triglycerides in food contain a mixture of saturated, monounsaturated, and polyunsaturated fatty acids, but some foods are better sources of these types of fatty acids than others (Figure 5.13). For example, coconut oil is very high in saturated fat, but it still contains some monounsaturated and polyunsaturated fatty acids. Peanut oil is often thought of as a good source of monounsaturated fat, because that is the predominant fatty acid in the oil, but peanut oil also contains a fair amount of polyunsaturated fatty acids and even some saturated fatty acids.

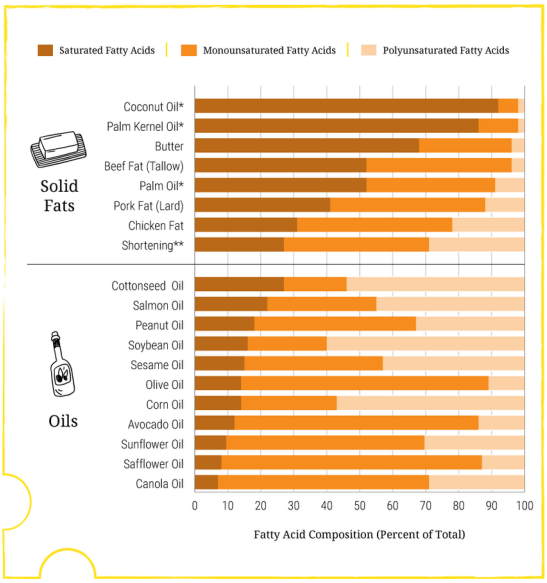


Figure 6.4.2: Dietary fats contain a mixture of saturated, monounsaturated, and polyunsaturated fatty acids. Foods are often categorized by the predominant type of fatty acids they contain, even though foods contain all three types. (Copyright; author via source)

Saturated Fatty Acids

Fat sources with a high percentage of **saturated fatty acids tend to be solid at room temperature**. This is because the lack of double bonds in the carbon chains of saturated fatty acids makes them very straight, so they pack together well (like a box of toothpicks). Fats that have mostly saturated fatty acids, like butter and coconut oil, are solid at room temperature, as are the visible fat layers in a strip of bacon or a cut of beef. Consuming a diet high in saturated fats is associated with an increased risk of heart disease, because such a diet increases blood cholesterol, specifically the LDL ("bad") cholesterol level. (More on this later.) **Food sources of predominately saturated fatty acids** include most animal fats (with the exception of poultry and eggs, which contain more unsaturated fatty acids), dairy products, tropical oils (like coconut and palm oil), cocoa butter, and partially or fully hydrogenated oils.



Figure 6.4.3: Examples of foods high in saturated fat, such as meat and dairy products

Unsaturated Fatty Acids

Fat sources rich in **unsaturated fatty acids tend to be liquid at room temperature**, because the C=C double bonds create bends in the carbon chain, making it harder for fatty acids to pack together tightly. Consuming a diet rich in mono- and polyunsaturated fats is associated with a lower LDL cholesterol level and a lower risk of heart disease.

Food sources of predominately monounsaturated fats include nuts and seeds like almonds, pecans, cashews, and peanuts; plant oils like canola, olive, and peanut oils; and avocados. The fat in poultry and eggs is predominantly unsaturated and contains more monounsaturated than polyunsaturated fatty acids..



Figure 6.4.4: Examples of foods high in monounsaturated fat, such as olive oil, avocado, nut butters, and seeds. (Copyright; author via source)

Food sources of predominately polyunsaturated fats include plant oils (soybean, corn); fish; flaxseed; and some nuts like walnuts and pecans.

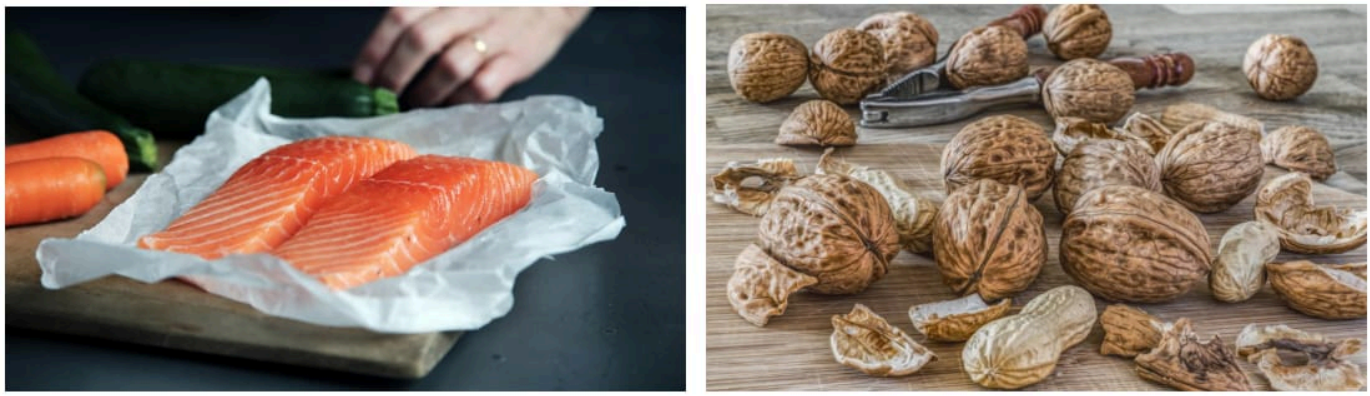


Figure 5.16. *Examples of foods high in polyunsaturated fats, like fish and nuts*

Omega-3, Omega-6, and Essential Fatty Acids

In addition to the length of the carbon chain and the number of double bonds, **unsaturated fatty acids are also classified by the position of the first double bond relative to the methyl (-CH_3) or "omega" end of the carbon chain** (the end furthest from the glycerol backbone in a triglyceride). Fatty acids with the first double bond at the third carbon from the omega end are called ***omega-3 fatty acids***. Those with the first double bond at the sixth carbon from the omega end are called ***omega-6 fatty acids***. (There are also omega-9 fatty acids.)

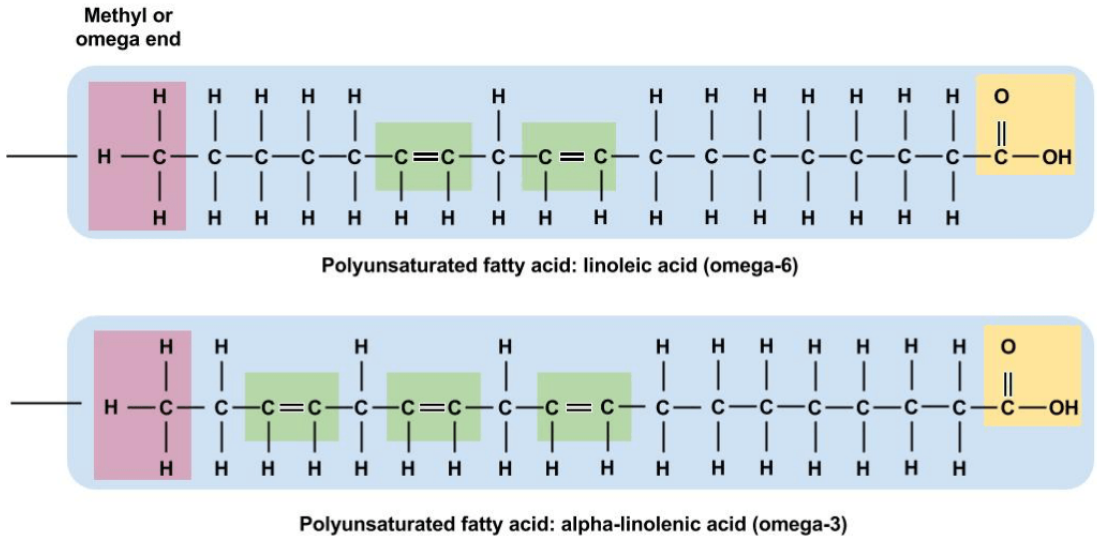
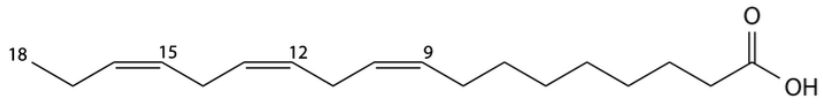
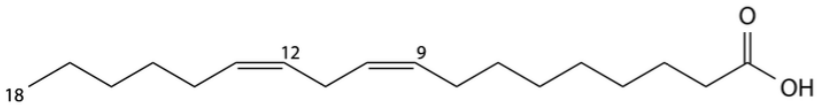


Figure 6.4.6: The position of the first C=C double bond determines whether an unsaturated fatty acid is classified as omega-3 or omega-6. The two essential fatty acids, linoleic acid (an omega-6) and alpha-linolenic acid (an omega-3) are shown here.

Fatty acids are vital for the normal operation of all body systems, but the body is capable of synthesizing most of the fatty acids it needs. However, there are two fatty acids that the body cannot synthesize: ***linoleic acid*** (an omega-6) and ***alpha-linolenic acid*** (ALA, an omega-3). These are called ***essential fatty acids*** because they must be consumed in the diet. Other fatty acids are called nonessential fatty acids, but that doesn't mean they're unimportant; the classification is based solely on the ability of the body to synthesize the fatty acid. Excellent **food sources of linoleic fatty acid** include plant oils such as corn oil and soybean oil, often found in salad dressings and margarine. **Rich food sources of alpha-linolenic acid (ALA)** include nuts, flaxseed, whole grains, legumes, and dark green leafy vegetables.



Alpha-linolenic acid (ALA). Note the first double bond occurs at the third carbon from the omega end of the fatty acid, thus making it an omega-3 fatty acid.



Linoleic acid. Note the first double bond occurs at the sixth carbon from the omega end of the fatty acid, thus making it an omega-6 fatty acid.

Figure 6.4.7: The chemical structure of the essential fatty acids shown in shorthand, without individual carbon and hydrogen atoms marked.

Most Americans easily consume enough linoleic acid and other omega-6 fatty acids, because corn and soybean oil are common ingredients in our food supply. However, sources of ALA and other omega-3 fatty acids are less common in the American diet, and many people could benefit from incorporating more sources of these into their diet. As an added benefit, whole foods rich in ALA come packaged with other healthful nutrients, like fiber, protein, vitamins, minerals, and phytochemicals.

A true **essential fatty acid deficiency** is rare in the developed world, but it can occur, usually in people who eat very low-fat diets or have impaired fat absorption. Symptoms include dry and scaly skin, poor wound healing, increased vulnerability to infections, and impaired growth in infants and children.[1]

Omega-3 and omega-6 fatty acids are precursors to a large family of important signaling molecules called ***eicosanoids*** (prostaglandins are one type of eicosanoid). Among the many functions of eicosanoids in the body, one of the most important is to regulate inflammation. Without these hormone-like molecules, the body would not be able to heal wounds or fight off infections each time a foreign germ presented itself. In addition to their role in the body's immune and inflammatory processes, eicosanoids also help to regulate circulation, respiration, and muscle movement.

Eicosanoids derived from omega-6 fatty acids tend to increase blood pressure, blood clotting, immune response, and inflammation. These are necessary functions, but they can be associated with disease when chronically elevated. In contrast, eicosanoids derived from omega-3 fatty acids tend to lower blood pressure, inflammation, and blood clotting, functions that can benefit heart health. Omega-3 and omega-6 fatty acids compete for the same enzymatic pathways in the formation of different eicosanoids, so increasing omega-3 fatty acids in the diet may have anti-inflammatory effects.

Two additional omega-3 fatty acids with important health benefits are ***eicosapentaenoic acid (EPA)*** and ***docosahexaenoic acid (DHA)***. These long-chain polyunsaturated fatty acids have been shown to help lower blood triglycerides and blood pressure, reduce inflammation, and prevent blood clot formation. They also promote normal growth and development in infants, especially in the development of the brain and eyes. Both of these important omega-3 fatty acids can be synthesized in the body from ALA, so **they are not considered essential fatty acids**. However, the rate of conversion of ALA to these omega-3s is limited, so it is beneficial to consume them regularly in the diet. **Fish, shellfish, fish oils, seaweed, and algae are all good sources of EPA and DHA**. DHA is also found in human breast milk in quantities dependent on the mother's own intake of DHA sources.

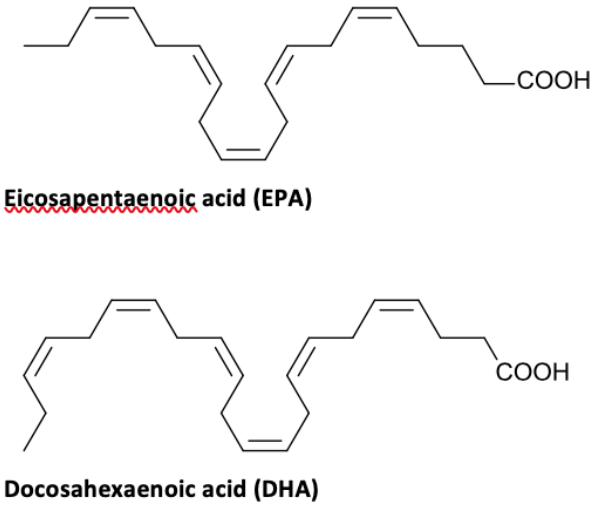


Figure 6.4.8: EPA and DHA are important but non-essential omega-3 fatty acids that can be made in the body from ALA.

Fish oil and omega-3 supplements are among the most commonly used dietary supplements in the United States. Researchers have hypothesized that these supplements might decrease risk of cardiovascular disease, be helpful for those with rheumatoid arthritis, and improve infant brain development when taken in pregnancy or in infancy. Some studies have found such benefits of the supplements, but others haven't. One reason for these inconsistent results may be that studies often don't measure participants' baseline omega-3 levels and intake from foods, and those already consuming adequate omega-3s are less likely to benefit from a supplement. The Dietary Guidelines for Americans recommends consuming 8 ounces of a variety of seafood each week, and in general, people who meet this recommendation likely consume enough omega-3 fatty acids already (along with the other healthful nutrients found in fish) and are unlikely to see an added benefit of taking a fish oil supplement. Some doctors may recommend that people at risk of cardiovascular disease take a fish oil or omega-3 supplement, especially if they don't eat fish regularly.[2]

A Word About *Trans* Fats

The carbon-carbon double bond in an unsaturated fatty acid chain can result in different shapes depending on whether the fatty acid is in a *cis* or *trans* configuration. When the hydrogen atoms are bonded to the same side of the carbon chain, it is called a *cis* fatty acid. Because the hydrogen atoms are on the same side (and repelling one another), the carbon chain has a bent structure. Naturally-occurring fatty acids usually have a *cis* configuration.

In a ***transfatty acid***, the hydrogen atoms are bonded on opposite sides of the carbon chain, resulting in a more linear structure. Unlike *cis* fatty acids, most *trans* fatty acids are not found naturally in foods, but instead are a result of an industrial process called hydrogenation. ***Hydrogenation*** is the process of adding hydrogen to the carbon-carbon double bonds, thus making the fatty acid saturated (or less unsaturated, in the case of partial hydrogenation).

Hydrogenation creates both saturated and trans fatty acids. Trans fatty acids are actually unsaturated fatty acids, but they have the linear shape of saturated fatty acids. (The carbon chains are not bent like naturally-occurring unsaturated fats.) **The trans fatty acids formed through partial hydrogenation have an unusual shape, which makes their properties and actions in the body similar to saturated fatty acids.**

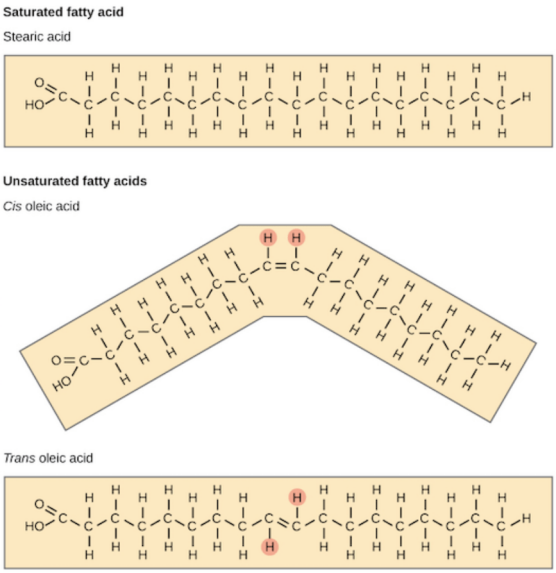


Figure 6.4.9: Comparison of a saturated fatty acid to both the cis and trans forms of an unsaturated fatty acid.

Hydrogenation was developed in order to make oils semi-solid at room temperature, enabling production of spreadable margarine and shortening from inexpensive ingredients like corn oil. Hydrogenation also makes oils more stable and less likely to go rancid, so partially hydrogenated oils were favored by fast food restaurants for frying, and manufacturers of processed baked goods like cookies and chips found they gave their products a longer shelf life. And because trans fats are unsaturated, nutrition scientists and the medical community believed that they were a healthier alternative to saturated fats.

But around the 1990s, evidence that trans fats were not healthy—far worse than saturated fats, in fact—began to accumulate. Like saturated fat, **trans fats increase LDL ("bad") cholesterol, but they also have the effect of decreasing HDL ("good") cholesterol** and of increasing inflammatory processes in the body. Researchers found that consuming trans fats, even at low levels (1 to 3 percent of total energy intake), was associated with an increased risk of coronary heart disease. They estimated that eliminating industrial trans fats from the food supply might prevent as many as 19 percent of heart attacks in the U.S. at the time, coming to 228,000 heart attacks averted.[3]

In 2006, the U.S. Food and Drug Administration (FDA) began requiring food companies to list trans fat information on the Nutrition Facts panel of food labels to keep consumers informed of their intake of these fats. That prompted the food industry to mostly eliminate partially hydrogenated oils from their products, often substituting palm oil and coconut oil in their place (both of which are high in saturated fat and may promote heart disease). In 2013, the FDA determined that trans fats were no longer considered safe in the food supply, and in 2015, the agency issued a ruling requiring that manufactured trans fats no longer be included in the U.S. food supply. A one-year extension was granted in 2018, and foods produced prior to that date were given time to work through the food supply. The final ruling requires all manufactured trans fats to be eliminated from the U.S. food supply by 2021.[4]

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6.5: Digestion and Absorption of Lipids

Lipid digestion and absorption pose some special challenges. Triglycerides are large molecules, and unlike carbohydrates and proteins, they're not water-soluble. Because of this, they like to cluster together in large droplets when they're in a watery environment like the digestive tract. The digestive process has to break those large droplets of fat into smaller droplets and then enzymatically digest lipid molecules using enzymes called ***lipases***. The mouth and stomach play a small role in this process, but most enzymatic digestion of lipids happens in the small intestine. From there, the products of lipid digestion are absorbed into circulation and transported around the body, which again requires some special handling since lipids are not water-soluble and do not mix with the watery blood.



Let's start at the beginning to learn more about the path of lipids through the digestive tract.

Lipid Digestion in the Mouth

A few things happen in the mouth that start the process of lipid digestion. Chewing mechanically breaks food into smaller particles and mixes them with saliva. An enzyme called ***lingual lipase*** is produced by cells on the tongue ("lingual" means relating to the tongue) and begins some enzymatic digestion of triglycerides, cleaving individual fatty acids from the glycerol backbone.

Lipid Digestion in the Stomach

In the stomach, mixing and churning helps to disperse food particles and fat molecules. Cells in the stomach produce another lipase, called ***gastric lipase*** ("gastric" means relating to the stomach) that also contributes to enzymatic digestion of triglycerides. ***Lingual lipase*** swallowed with food and saliva also remains active in the stomach. But together, these two lipases play only a minor role in fat digestion (except in the case of infants, as explained below), and most enzymatic digestion happens in the small intestine.

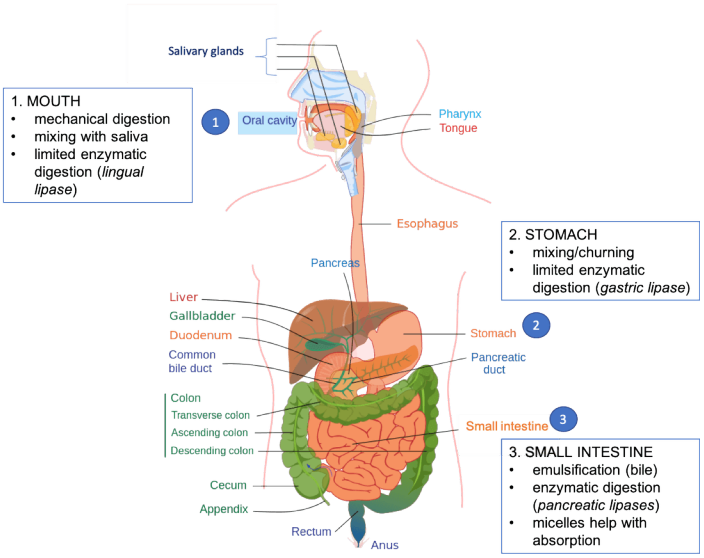


Figure 6.5.1: Overview of lipid digestion in the human gastrointestinal tract. (Copyright; author via source)

Lipid Digestion in the Small Intestine

As the stomach contents enter the small intestine, most of the dietary lipids are undigested and clustered in large droplets. ***Bile***, which is made in the liver and stored in the gallbladder, is released into the duodenum, the first section of the small intestine. Bile salts have both a hydrophobic and a hydrophilic side, so they are attracted to both fats and water. This makes them effective emulsifiers, meaning that they break large fat globules into smaller droplets. Emulsification makes lipids more accessible to digestive enzymes by increasing the surface area for them to act (see Fig. *5.22* below).

The pancreas secretes ***pancreatic lipases*** into the small intestine to enzymatically digest triglycerides. Triglycerides are broken down to fatty acids, monoglycerides (glycerol backbone with one fatty acid still attached), and some free glycerol. Cholesterol and fat-soluble vitamins do not need to be enzymatically digested (see Fig. *5.22* below).

Lipid Absorption from the Small Intestine

Next, those products of fat digestion (fatty acids, monoglycerides, glycerol, cholesterol, and fat-soluble vitamins) need to enter into the circulation so that they can be used by cells around the body. Again, bile helps with this process. Bile salts cluster around the products of fat digestion to form structures called ***micelles***, which help the fats get close enough to the microvilli of intestinal cells so that they can be absorbed. The products of fat digestion diffuse across the membrane of the intestinal cells, and bile salts are recycled back to do more work emulsifying fat and forming micelles.

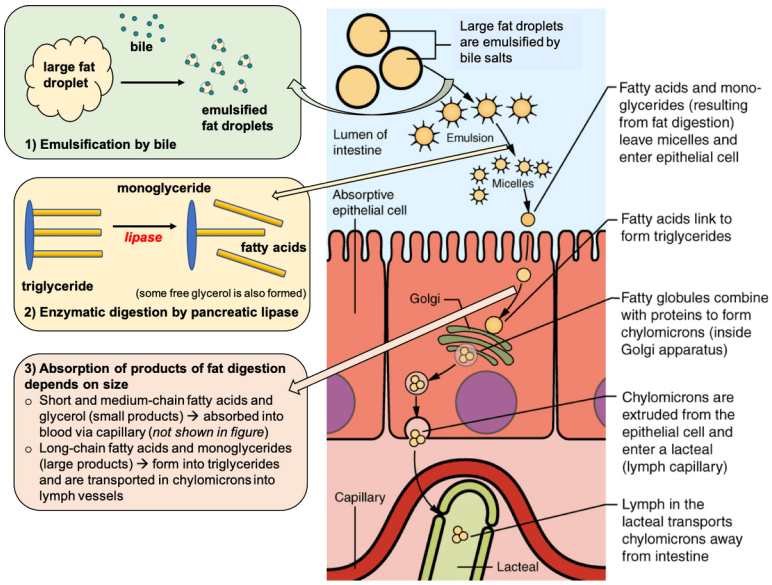


Figure 6.5.1: Lipid digestion and absorption in the small intestine. (Copyright; author via source)

Once inside the intestinal cell, short- and medium-chain fatty acids and glycerol can be directly absorbed into the bloodstream, but larger lipids such as long-chain fatty acids, monoglycerides, fat-soluble vitamins, and cholesterol need help with absorption and transport to the bloodstream. Long-chain fatty acids and monoglycerides reassemble into triglycerides within the intestinal cell, and along with cholesterol and fat-soluble vitamins, are then incorporated into transport vehicles called chylomicrons. ***Chylomicrons*** are large structures with a core of triglycerides and cholesterol and an outer membrane made up of phospholipids, interspersed with proteins (called apolipoproteins) and cholesterol. This outer membrane makes them water-soluble so that they can travel in the aqueous environment of the body. Chylomicrons from the small intestine travel first into lymph vessels, which then deliver them to the bloodstream.

Chylomicrons are one type of lipoprotein—transport vehicles for lipids in blood and lymph. We'll learn more about other types of lipoproteins on the next page.

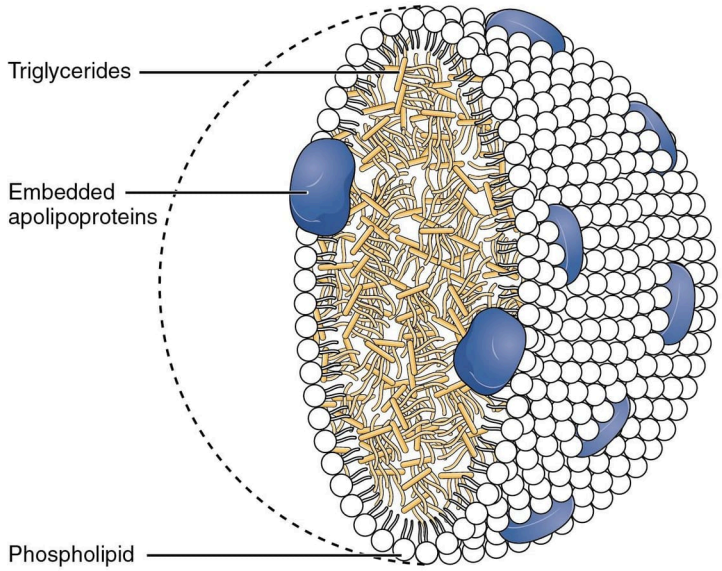
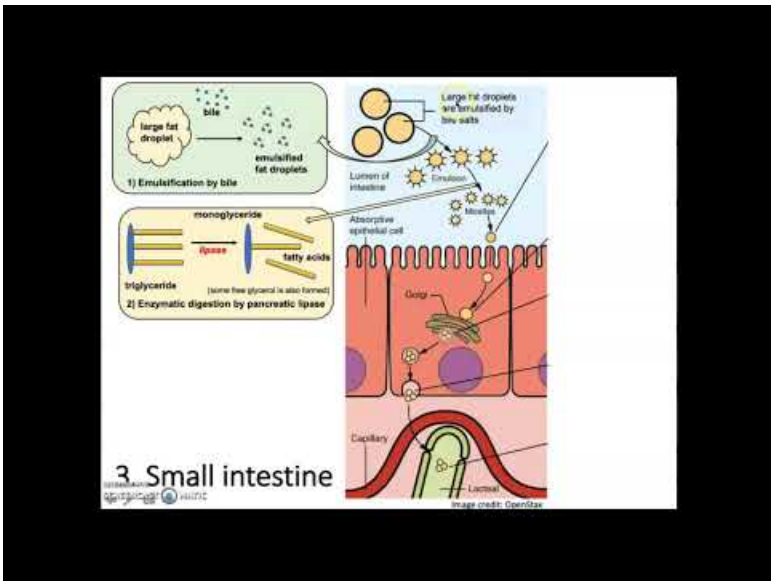


Figure 6.5.1: Structure of a chylomicron. Cholesterol is not shown in this figure, but chylomicrons contain cholesterol in both the lipid core and embedded on the surface of the structure. (Copyright; author via source)



Special Adaptations for Lipid Digestion in Infants

Lipids are an important part of an infant's diet. Breast milk contains about 4 percent fat, similar to whole cow's milk. Whether breastfed or formula-fed, fat provides about half of an infant's calories, and it serves an important role in brain development. Yet, infants are born with low levels of bile and pancreatic enzyme secretion, which are essential contributors to lipid digestion in older children and adults. So, how do babies digest all of the fat in their diet?

Infants have a few special adaptations that allow them to digest fat effectively. First, they have plenty of lingual and gastric lipases right from birth. These enzymes play a much more important role in infants than they do in adults. Second, breast milk actually contains lipase enzymes that are activated in the baby's small intestine. In other words, the mother makes lipases and sends them in breast milk to help her baby digest the milk fats. Amazing, right? **Between increased activity of lingual and gastric lipases and the lipases contained in breast milk, young infants can efficiently digest fat and reap its nutritional value for growth and brain development.** Studies show that fat digestion is more efficient in premature infants fed breast milk compared with those fed formula. Even pasteurized breast milk, as is used when breast milk is donated for feeding babies in the hospital, is a little harder to digest, because heat denatures the lipases. (Infants can still digest pasteurized breast milk and formula; they're just less efficient at doing so and absorb less of the products of triglyceride digestion.)[1]



Figure 6.5.1: Copy and Paste Caption here. (Copyright; author via source)

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6.6: Lipid Transport, Storage, and Utilization

Once dietary lipids are digested in the gastrointestinal tract and absorbed from the small intestine, they need to be transported around the body so they can be utilized by cells or stored for later use. Once again, the fact that lipids aren't water-soluble means that they need some help getting around the watery environment of the body. Let's take a look at how this works.

Lipoproteins Transport Lipids Around the Body

Lipoproteins are transport vehicles for moving water-insoluble lipids around the body. There are different types of lipoproteins that do different jobs. However, all are made up of the same four basic components: cholesterol, triglycerides, phospholipids, and proteins.

The interior of a lipoprotein—called the lipid core—carries the triglycerides and cholesterol esters, both of which are insoluble in water. ***Cholesterol esters*** are cholesterol molecules with a fatty acid attached. The exterior of lipoproteins—called the surface coat—is made up of water-soluble components: proteins (called ***apolipoproteins***), phospholipids, and unesterified cholesterol. The phospholipids are oriented so that their water-soluble heads are pointed to the exterior, and their fat-soluble tails are pointed towards the interior of the lipoprotein.

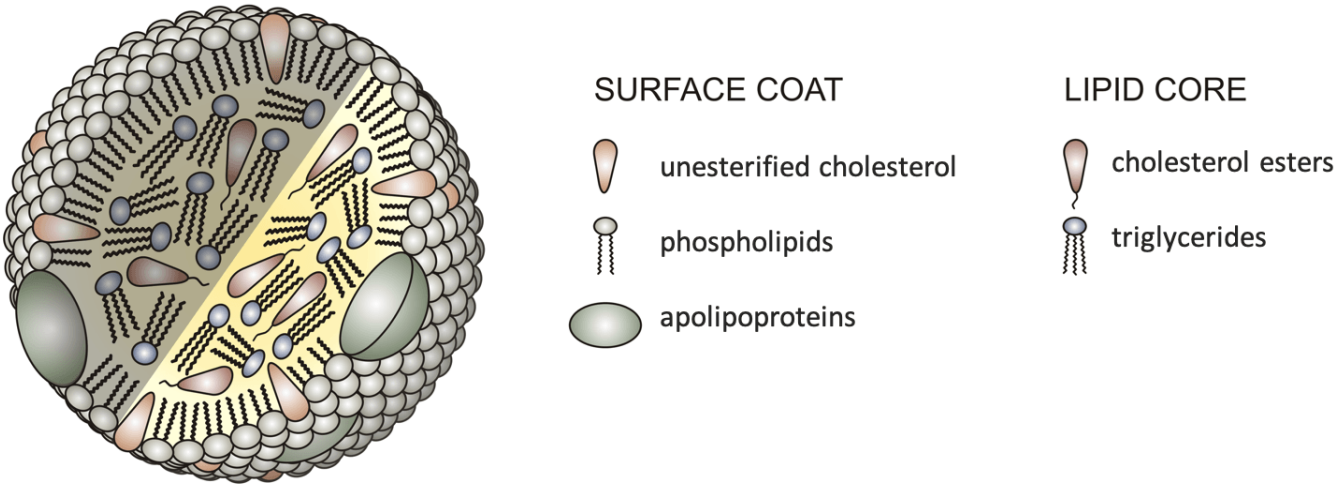


Figure 6.6.1: Basic structure of all lipoproteins. Note the orientation of phospholipids on the surface coat. ("Structure of a Lipoprotein" by AntiSense is licensed under CC BY-SA 3.0)

While all lipoproteins have this same basic structure and contain the same four components, different types of lipoproteins vary in the relative amounts of the four components, in their overall size, and in their functions. These are summarized in the graph and table below, and the following sections give more details on the role of each type of lipoprotein.

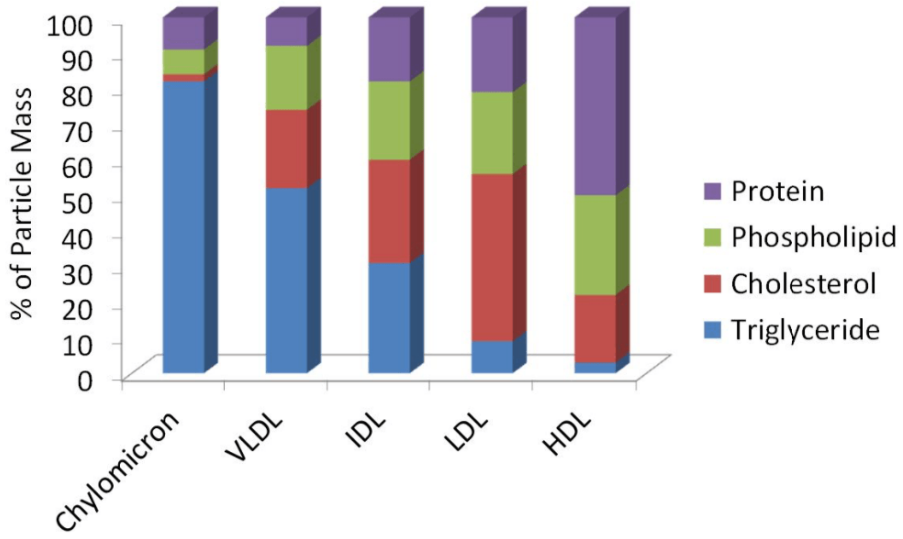


Figure 6.6.1: Comparison of composition of lipoproteins. ("Storing and Using Fat" by Allison Calabrese is licensed under CC BY 4.0; with modifications by Alice Callahan.)

	Chylomicrons	**Very-low-density lipoproteins (VLDL)**	**Intermediate-density lipoproteins (IDL)**	**Low-density lipoproteins (LDL)**	**High-density lipoproteins (HDL)**
Diameter (nm)	75-1200 (largest)	30-80	25-35	18-25	5-12 (smallest)
Density (g/dL)	0.95 (least dense)	0.95-1.006	1.006-1.019	1.019-1.063	1.063 (most dense)
Function	Transports lipids from the small intestine, delivers TG to the body's cells	Transports lipids from the liver, delivers TG to body's cells	Formed as VLDL become depleted in TG; either returned to liver or made into LDL	Deliver cholesterol to cells	Pick up cholesterol in the body and return to the liver for disposal

Table 5.1. Comparison of composition, size, density, and function of lipoproteins. (TG = triglycerides)

Except for chylomicrons, the names of the lipoproteins refer to their density. Of the four components of lipoproteins, protein is the most dense and triglyceride is the least dense. (This is why one pound of muscle is much more compact in size than one pound of adipose or fat tissue.) High-density lipoproteins are the most dense of the lipoproteins, because they contain more protein and less triglyceride. Chylomicrons are the least dense, because they contain so much triglyceride and relatively little protein.

Chylomicrons Deliver Lipids to Cells for Utilization and Storage

On the previous page, we learned that chylomicrons are formed in the cells of the small intestine, absorbed into the lymph vessels, and then eventually delivered into the bloodstream. **The job of chylomicrons is to deliver triglycerides (originating from digested food) to the cells of the body**, where they can be used as an energy source or stored in adipose tissue for future use.

How do the triglycerides get from the chylomicrons into cells? An enzyme called ***lipoprotein lipase*** sits on the surface of cells that line the blood vessels. It breaks down triglycerides into fatty acids and glycerol, which can then enter nearby cells. If those cells need energy right away, they'll oxidize the fatty acids to generate ATP. If they don't need energy right away, they'll reassemble the fatty acids and glycerol into triglycerides and store them for later use.

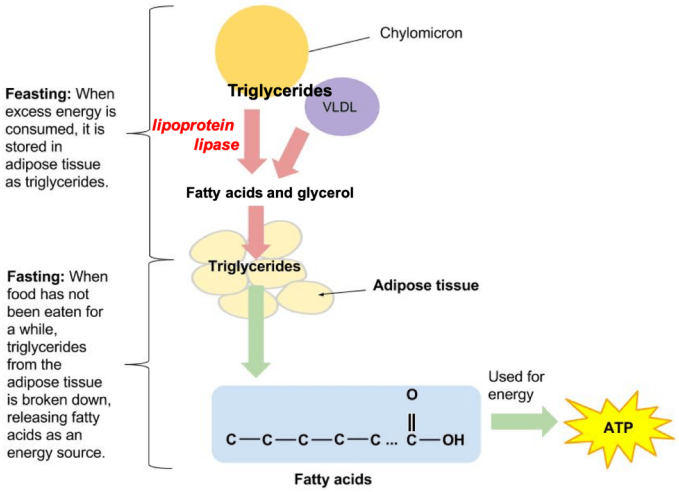


Figure 6.6.2: Triglycerides in chylomicrons and VLDL are broken down by lipoprotein lipase so that fatty acids and glycerol can be used for energ y—or stored for later—in cells. (*Comparison of composition, size, density, and function of lipoproteins* by Alice Callahan, CC BY 4.0, including Figure 4.712 from Lindshield, B. L. Kansas State University Human Nutrition (FNDH 400) Flexbook. goo.gl/vOAnR, CC BY-NC-SA 4.0)

As triglycerides are removed from the chylomicrons, they become smaller. These chylomicron remnants travel to the liver, where they're disassembled.

Lipid Transport from the Liver

The contents of chylomicron remnants, as well as other lipids in the liver, are incorporated into another type of lipoprotein called ***very-low-density lipoprotein (VLDL)***. Similar to chylomicrons, the main job of VLDL is delivering triglycerides to the body's cells, and lipoprotein lipase again helps to break down the triglycerides so that they can enter cells (Figure 5.27).

As triglycerides are removed from VLDL, they get smaller and more dense, because they now contain relatively more protein compared to triglycerides. They become ***intermediate-density lipoproteins (IDL)*** and eventually ***low-density lipoproteins (LDL)***. The main job of LDL is to deliver cholesterol to the body's cells. Cholesterol has many roles around the body, so this is an important job. However, too much LDL can increase a person's risk of cardiovascular disease, as we'll discuss below.

High-density lipoproteins (HDL) are made in the liver and gastrointestinal tract. They're mostly made up of protein, so they're very dense. Their job is to pick up cholesterol from the body's cells and return it to the liver for disposal.

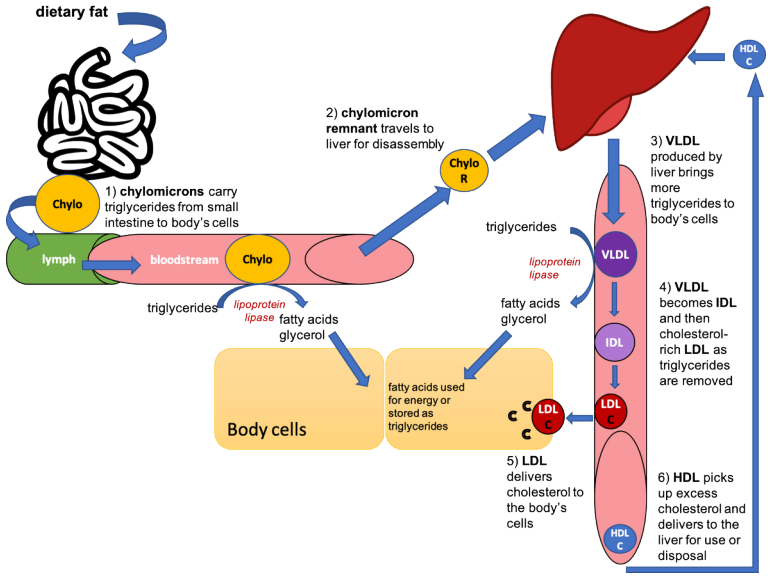


Figure 6.6.3: Overview of lipoprotein functions in the body. (Overview of lipoprotein transport and delivery by Alice Callahan is licensed under CC BY 4.0; with liver by maritacovarrubias and small intestine by H Alberto Gongora, both from the Noun Project, CC BY 3.0)

VIDEO: "Cholesterol Metabolism, LDL, HDL, and Other Lipoproteins, Animation," by Alila Medical Media, YouTube (May 1, 2018), 3:45 minutes.

YouTube Video

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Does Eating a Higher Fat Diet Mean You Will Store More Fat?

No. How much fat a person stores depends on how many calories they consume relative to how many calories they need to fuel their body. If they consume more calories than needed to meet their body's daily needs—whether those calories come from dietary fat, carbohydrate, or protein—then they'll store most of the excess calories in the form of fat in adipose tissue. If they consume a high-fat diet but not excess calories, then they'll utilize that fat to generate ATP for energy. That said, remember that fat is more calorically dense (9 kilocalories per gram) than protein or carbohydrates (both 4 kcal/g), so if you eat a high-fat diet, you may need to eat smaller portions. And, as we'll discuss later in this unit, there are good reasons to watch the *type* of fats that you eat, because of the relationship between dietary fat intake and risk of developing cardiovascular disease.

Understanding Blood Cholesterol Numbers

A person's blood cholesterol numbers can be one indicator of their risk of developing cardiovascular disease. This is a standard blood test, also called a ***lipid panel***, that reports total cholesterol, LDL, HDL, and triglycerides. When doctors assess a person's risk of cardiovascular disease, they consider these numbers—along with other risk factors like family history, smoking, diabetes, and high blood pressure—in determining their recommendations for lifestyle changes (such as improving diet and getting more exercise) or prescribing medications.

You might be familiar with LDL and HDL as "**good cholesterol**" and "**bad cholesterol**," respectively. This is an oversimplification to help people interpret their blood lipid values, because cholesterol is cholesterol; it's not good or bad. **The cholesterol in your**

food or synthesized in your body is all the same cholesterol molecule, and you can't consume good or bad cholesterol. In reality, LDL and HDL are both lipoproteins that carry cholesterol. A more appropriate descriptor for LDL might be the "bad cholesterol transporter." We can think of HDL as the "good cholesterol transporter," although the more researchers learn about HDL, the more they realize that this is also an oversimplification.

What's so bad about LDL? **If there's too much LDL in the blood, it can become lodged in arterial walls and contribute to the development of *atherosclerosis***, when fatty plaques thicken the walls of arteries and reduce the flow of blood (and therefore oxygen and nutrients). Atherosclerosis can lead to a number of problems, including the following:

- coronary artery disease (can lead to angina and heart attack)
- carotid artery disease (increases risk of stroke)
- peripheral artery disease
- chronic kidney disease

If a broken piece of plaque or a blood clot completely blocks an artery supplying the brain or the heart, it can cause a stroke or a heart attack, respectively. If you have high LDL cholesterol, then making changes like exercising more, eating less saturated fat, and stopping smoking (if applicable) can help lower it. Sometimes medications are also necessary to keep LDL in check.

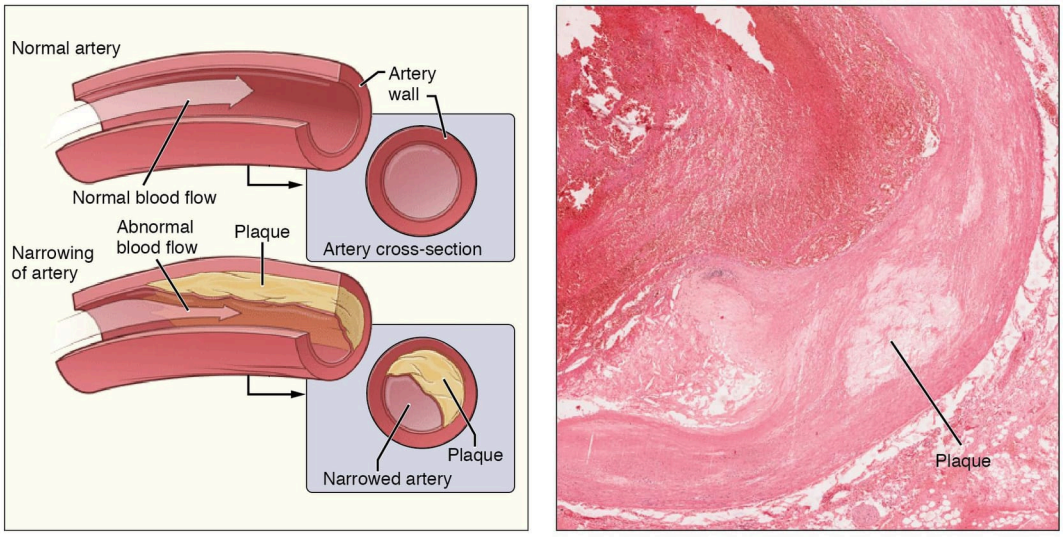


Figure 6.6.1: Atherosclerosis. (a) Atherosclerosis can result from plaques formed by the buildup of fatty, calcified deposits in an artery. (b) Plaques can also take other forms, as shown in this micrograph of a coronary artery that has a buildup of connective tissue within the artery wall. LM × 40. (Micrograph provided by the Regents of University of Michigan Medical School © 2012) ("Atherosclerosis" by OpenStax is licensed under CC BY 4.0)

Physicians sometimes run additional blood tests to measure the LDL particle size and the number of LDL particles. The standard LDL test measures the total *amount* of cholesterol that is carried by LDL, but the reality is that LDL comes in a range of sizes, and small LDL particles are more strongly associated with the risk of atherosclerosis and cardiovascular disease than large LDL particles. For two people with the same total LDL cholesterol measurement, a person with more small particles will have a greater *number* of LDL particles circulating and a higher risk of developing heart disease. A person with more large LDL particles will have fewer particles overall and a lower risk of developing heart disease. Measuring particle size is not recommended for all patients because of the cost of the test and the fact that it rarely changes treatment course or improves outcomes. However, it can be useful in patients with diabetes or insulin resistance, as they tend to have more small LDL particles, which may call for using medications sooner or in higher doses.

HDL has been considered the "good cholesterol" or "good cholesterol transporter" because it scavenges cholesterol, including LDL lodged in the arterial walls, and helps to remove it from the body. Previously, it was thought that high HDL could prevent atherosclerosis and protect people from cardiovascular disease. But over the last few years, researchers have discovered that this view of HDL is oversimplified. Pharmaceutical companies developed drugs to raise HDL, thinking this would help to prevent cardiovascular disease. When these medications were tested in clinical trials, they were effective at raising HDL, but they didn't decrease the incidence of heart attack, stroke, angina, or death from cardiovascular disease.[1] In one clinical trial, the incidence of cardiovascular events and death from any cause were actually increased in people who took the HDL-raising

medication (2). Genetic studies have also shown that people with genes for higher HDL don't necessarily have a lower risk of developing cardiovascular disease.[3] People with low HDL cholesterol do seem to have a higher risk of cardiovascular disease, but they also tend to have other risk factors like sedentary lifestyle, smoking, and diabetes. It's not clear that low HDL is actually a *cause* of cardiovascular disease; we only know that it's correlated. Because of these discoveries, raising HDL cholesterol is no longer considered a goal of prevention of heart disease. Rather, lowering LDL cholesterol is the primary target.[4,5]

Considerations for Transgender and Gender-diverse Individuals

On the biochemical and clinical lab side, evaluators should include lipid profile including HDL-cholesterol. Decreased HDL is likely/more typical in masculinizing therapies (testosterone) for transmasculine individuals (assigned female at birth). Transfeminine individuals (assigned male at birth) on estrogen can experience favorable lipid effects (Ferrero, 2023). Over time, clinicians should monitor bone density, especially in those receiving gonadal suppression or inconsistent hormone dosing.

Gender-affirming nutrition care demands flexibility: selecting or blending reference values based on hormonal state, tracking body composition changes rather than overreliance on rigid cutoffs, and anchoring nutrient recommendations in individualized lab data. Because the evidence base remains limited, ongoing data collection, research, and shared decision-making with clients are foundational to advancing best practice in this domain (Sousa et al., 2024; Gold et al., 2024).

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6.7: Lipid Recommendations and Heart Health

"In past decades, dietary guidance has almost universally advocated reducing the intake of total and saturated fat, with the emphasis shifting more recently from total fat to the replacement of saturated fat with polyunsaturated fats and the elimination of trans fat. These recommendations and the link between fat consumption and the risk of cardiovascular disease have been among the most vexed issues in public health: are dietary fats "villains," are they benign, or are they even "heroes" that could help us consume better overall diets and promote health?"

This quote from a 2018 analysis on diet and heart health in the medical journal, *The BMJ,* sums up the challenge of making recommendations for dietary fat intake. You may reason that if some fats are healthier than other fats, why not eliminate all "bad" fats and consume as much healthy fat as desired? Remember, everything in moderation. As we review the established guidelines for daily fat intake, we'll explain the importance of balancing fat consumption with proper fat sources.

Lipids and Disease

Heart disease is the leading cause of death in the United States, claiming the lives of nearly 650,000 Americans in 2017. Deaths from stroke, which shares many of the same risk factors, accounts for an additional 150,000 fatalities each year. The burden of cardiovascular disease makes it critical to address dietary and lifestyle choices that can decrease risk factors for these diseases. According to the American Heart Association, the following **risk factors for heart disease are modifiable**, meaning they can be managed or changed by the individual:

- high blood pressure
- high blood cholesterol
- tobacco use
- diabetes
- poor diet
- physical inactivity
- overweight or obesity

In light of these risk factors, there are many dietary strategies related to fat intake that can reduce the risk of heart disease. The amount and type of fat that a person eats can have a profound effect on the way their body metabolizes fat and cholesterol.

If left unchecked, improper dietary fat consumption can lead down a path to severe health problems. An elevated level of lipids—including triglycerides and cholesterol—in the blood is called ***hyperlipidemia***. Many diseases and health conditions are associated with high blood lipid levels, including:

- Cardiovascular disease
- Heart attack
- Stroke
- Congestive heart failure
- Obesity



Recommended Fat Intake

Because of the association between dietary fat consumption and hyperlipidemia, health experts have developed recommendations for fat intake to help guide food choices. The acceptable macronutrient distribution range (AMDR) from the Dietary Reference Intake Committee and recommendations for adult fat consumption from the Dietary Guidelines for Americans are as follows:

- **Fat calories should be limited to 20-35 percent of total calories, with most fats coming from polyunsaturated and monounsaturated fats**, such as those found in fish, nuts, and vegetable oils.
- **Consume fewer than 10 percent of calories from saturated fats**. Some studies suggest that lowering the saturated fat content to less than 7 percent can further reduce the risk of heart disease, but other studies contradict this recommendation.
- **Keep the consumption of trans fats (any food label that reads partially hydrogenated oil) as low as possible**. (As manufactured trans fats are being phased out of the U.S. food supply, Americans don't have to worry as much about identifying and avoiding trans fats. However, they're still used in other parts of the world.)
- Choose more lean and low-fat products when selecting meat, poultry, milk, and dairy products.

The Complicated Relationship of Saturated Fat with Heart Health

Being conscious of the need to reduce blood cholesterol levels to improve health often means limiting the consumption of saturated fats. Multiple studies have shown an association between the saturated fats found in some meat, whole-fat dairy products, butter, and tropical oils (coconut and palm oils) and higher LDL cholesterol levels. However, while saturated fats have a historical reputation for being unhealthy, more recent research has suggested that the link between saturated fat and heart disease may not be as clear cut as we once thought.

The BMJ's analysis on dietary fat and heart health explains the complicated relationship as such:

"Synergism and interactions between different components of foods together with the degree of processing and preparation or cooking methods lead to a 'food matrix' effect which is not captured by considering single nutrients. Different types of food that are high in saturated fats are likely to have different effects on health. For example, dairy products and processed meats, both high in saturated fats, are differentially associated with many health outcomes in prospective epidemiological studies, often in opposite directions. One explanation for this divergence is that despite their similar fat content, other components of these two food groups are associated with different health effects. For example, dairy products contain minerals such as calcium and magnesium and have probiotic features if fermented, whereas processed red meat has a high salt and preservative content.

To produce public health guidelines on which foods to eat or avoid to reduce the risk of chronic disease is complicated because dietary fats are typically mixtures of different types of fatty acids. Animal fats, for instance, are the main sources of saturated fats in many modern diets, but some animal fats are higher in monounsaturated fats than saturated fats, and polyunsaturated fats in

vegetable oils will typically contain both omega-3 and omega-6 fatty acids in different concentrations. Hence, conclusions about the health effects of saturated and polyunsaturated fatty acids are unlikely to consistently translate to the health effects of the fats, oils, and foods in which those fatty acids are present."

In an article from Tufts University Health & Nutrition Letter, *Links Between Saturated Fat, Blood Cholesterol & Heart Disease Prove Complex*, researcher Ronald M. Krauss, MD, said, "there is insufficient evidence from prospective epidemiological studies to conclude that dietary saturated fat is associated with an increased risk of cardiovascular disease (CVD)." Researchers state that reducing saturated fat intake may not clearly decrease CVD risk in part because people tend to replace saturated fat with processed carbohydrates. Recent studies have attempted to tease out different approaches to lowering saturated fat in the diet, showing that the types of foods used to replace saturated fat affect the risk of heart disease.

- If saturated fat in the diet is replaced with **unsaturated fats**, risk for heart disease **decreases.**
- If saturated fat in the diet is replaced with **refined carbohydrates**, risk for heart disease **increases.**



According to the 2015 DGA report, "**Strong and consistent evidence shows that replacing saturated fats with unsaturated fats, especially polyunsaturated fats, is associated with reduced blood levels of total cholesterol and of low-density lipoprotein-cholesterol (LDL-cholesterol)**. Additionally, strong and consistent evidence shows that replacing saturated fats with polyunsaturated fats is associated with a reduced risk of CVD events (heart attacks) and CVD-related deaths.

Some evidence has shown that replacing saturated fats with plant sources of monounsaturated fats, such as olive oil and nuts, may be associated with a reduced risk of CVD. However, the evidence base for monounsaturated fats is not as strong as the evidence base for replacement with polyunsaturated fats. Evidence has also shown that replacing saturated fats with carbohydrates reduces blood levels of total and LDL-cholesterol, but increases blood levels of triglycerides and reduces high-density lipoprotein-cholesterol (HDL-cholesterol). **Replacing total fat or saturated fats with carbohydrates is not associated with reduced risk of CVD**. Additional research is needed to determine whether this relationship is consistent across categories of carbohydrates (e.g., whole versus refined grains; intrinsic versus added sugars), as they may have different associations with various health outcomes. **Therefore, saturated fats in the diet should be replaced with polyunsaturated and monounsaturated fats.**"

Dr. Krauss summed up the recommendations as such: "An overall eating pattern that emphasizes whole grains rather than refined carbs such as white flour, along with foods high in polyunsaturated fats, such as fish, seeds, nuts and vegetable oils, is of more value for reducing coronary heart disease risk than simply aiming to further reduce saturated fat."



Figure 5.29. Examples of heart healthy meals, including fish, nuts, seeds, whole grains, and unsaturated fats

What About Seed Oils?

In recent years, seed oils such as soybean, canola, sunflower, and safflower oils have been the subject of growing public concern, often fueled by social media claims suggesting they are harmful or "toxic." However, extensive scientific evidence gathered over decades by researchers in nutrition, epidemiology, and public health consistently shows that these oils are safe and, when used appropriately, can support heart health. Seed oils are rich in polyunsaturated fatty acids (PUFAs), especially omega-6 linoleic acid, which help reduce LDL ("bad") cholesterol when they replace saturated fats from animal sources such as butter or beef tallow. Large-scale studies and clinical trials have linked higher intakes of unsaturated fats and lower intakes of saturated fats with reduced risk of cardiovascular disease.

Concerns about oxidation and rancidity in seed oils are valid from a food-quality standpoint but can be managed by storing oils in tightly sealed, opaque containers away from heat and light, and by using them within a reasonable time — well before their printed expiration dates. Consumers are encouraged to seek information from reputable sources such as the American Heart Association, the Dietary Guidelines for Americans, and peer-reviewed nutrition research, which provide evidence-based guidance on dietary fats and overall health.

What About Dietary Cholesterol?

Dietary cholesterol also has a small impact on overall blood cholesterol levels, but not as much as some people may think. For most people, decreasing dietary cholesterol intake has little impact on blood cholesterol, because their bodies respond by reducing synthesis of cholesterol in favor of using the cholesterol obtained from food. Genetic factors may also influence the way a person's body responds to changes in cholesterol intake. The 2015 U.S. Dietary Guidelines for Americans (DGA) suggest limiting saturated fats, thereby indirectly limiting dietary cholesterol since foods that are high in cholesterol tend to also be high in saturated fats. (Eggs and fish are notable exceptions; both are high in cholesterol but low in saturated fats.)

The 2015 DGA dropped the previous recommendation (from the 2010 DGA) to limit the consumption of dietary cholesterol to 300 mg per day, but with a caveat: "This change does not suggest that dietary cholesterol is no longer important to consider when building healthy eating patterns. As recommended by the Institute of Medicine, individuals should eat as little dietary cholesterol as possible while consuming a healthy eating pattern."

Practical Tips for a Heart Healthy Diet



- Focus on whole food sources of dietary fat, because they come packaged with vitamins, minerals, phytochemicals, and sometimes fiber and protein.
- Remember that saturated fats are found in large amounts in foods of animal origin. They should be limited within the diet.
- Some highly processed foods, such as stick margarines, cookies, pastries, crackers, fried foods, and snack foods are sources of saturated fat (and historically, trans fats) that can elevate your cholesterol levels, so use them sparingly.
- Fatty fish like salmon, tuna, and halibut are heart-healthy due to their high levels of omega-3 fatty acids, which can reduce inflammation and lower cholesterol levels. The American Heart Association recommends consuming fish—especially fatty fish—twice per week.
- Nuts and seeds contain high levels of unsaturated fatty acids that aid in lowering LDL when they replace saturated fat in the diet.
- Most plant-based oils (except tropical oils like palm and coconut oils) are good sources of polyunsaturated and monounsaturated fats and may help to lower LDL. Substitute oils for solid fats when possible.
- Choose whole-grain and high-fiber foods. Reduced risk for cardiovascular disease has been associated with diets that are high in whole grains and fiber. Fiber also slows down cholesterol absorption. The AHA recommends that at least half of daily grain intake come from whole grains.
- Soluble fiber reduces cholesterol absorption in the bloodstream. Plant-based foods rich in soluble fiber include oatmeal, oat bran, legumes, apples, pears, citrus fruits, barley, and prunes.
- Check out additional information on What is the Best Oil for Cooking?

In addition to dietary changes, don't forget the value of physical activity. Physical *inactivity* increases the risk of heart disease. Physical exercise can help manage or prevent high blood pressure and high blood cholesterol. Regular activity raises HDL while also decreasing triglycerides and plaque buildup in the arteries. And activity consistently burns calories, which can help with weight loss or maintaining a healthy weight.

YouTube Video

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VIDEO: "Fats – Biochemistry," by Osmosis, YouTube (February 14, 2018), 12 minutes. This video gives an overview of some of the

topics discussed in this unit, including the different types of fatty acids and their impact on health, and digestion and absorption of triglycerides.

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CHAPTER 7: PROTEIN AND AMINO ACIDS

Learning Objectives

After completing this unit, you should be able to:

1. Describe the basic chemical structure of all amino acids, and understand the difference between essential and non-essential amino acids.
2. Describe how proteins are formed from amino acids and name the four levels of structural organization of proteins. Appreciate how the structure of a protein is vital to its function.
3. Describe and give examples of the wide variety of different functions of proteins in the body.
4. Define the guidelines for protein intake, and identify food sources of protein in the diet, distinguishing between complete and incomplete proteins.
5. Trace the steps of protein digestion and absorption through the gastrointestinal tract, and discuss how absorbed amino acids are used by the body.
6. Identify the health consequences of too little and too much dietary protein.
7. Discuss the environmental and public health consequences of protein choices, and identify ways to make more sustainable choices.

7.1: Introduction to Protein

7.2: Protein Structure

7.3: Protein Functions

7.4: Protein in Foods and Dietary Recommendations

7.5: Protein Digestion and Absorption

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

7.7: Protein Food Choices and Sustainability

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7.1: Introduction to Protein

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



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7.2: Protein Structure

What Is Protein?

Proteins are macromolecules composed of amino acids. For this reason, ***amino acids*** are commonly called the building blocks of protein. There are 20 different amino acids, and we require all of them to make the many different proteins found throughout the body. Proteins are crucial for the nourishment, renewal, and continuance of life.

Just like carbohydrates and fats, proteins contain the elements carbon, hydrogen, and oxygen, but **proteins are the only macronutrient that also contain nitrogen** as part of their core structure. In each amino acid, the elements are arranged into a specific conformation, consisting of a central carbon bound to the following four components:

- A hydrogen
- A nitrogen-containing *amino* group
- A carboxylic *acid* group (hence the name “amino acid”)
- A side chain

The first three of those components are the same for all amino acids. The side chain—represented by an “R” in the diagram below—is what makes each amino acid unique.

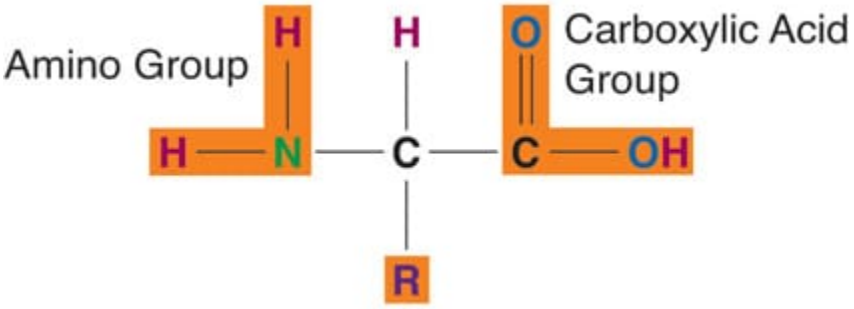


Figure 6.1. Amino Acid Structure.

Amino acid side chains vary tremendously in their size and can be as simple as one hydrogen (as in glycine, shown in Figure 6.1) or as complex as multiple carbon rings (as in tryptophan). They also differ in their chemical properties, thus impacting the way amino acids act in their environment and with other molecules. Because of their side chains, some amino acids are polar, making them hydrophilic and water-soluble, whereas others are nonpolar, making them hydrophobic or water-repelling. Some amino acids carry a negative charge and are acidic, while others carry a positive charge and are basic. Some carry no charge. Some examples are given below. For this class, you don’t need to memorize amino acid structures or names, but you should appreciate the diversity of amino acids and understand that it is the side chain that makes each different.

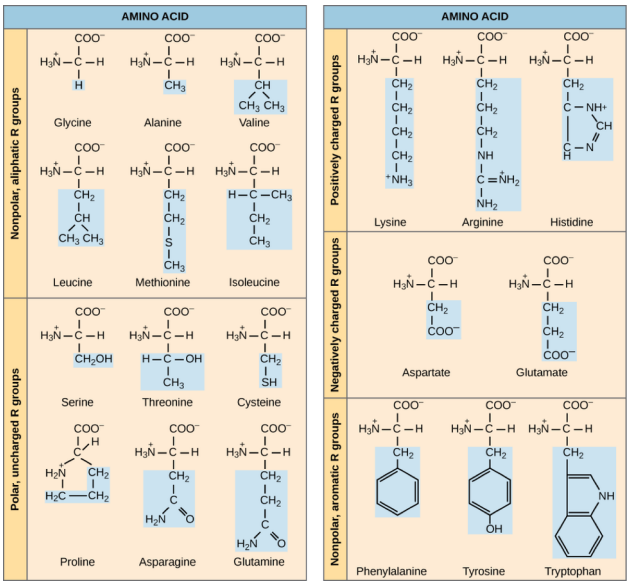


Figure 6.2. Amino acids have different structures and chemical properties, determined by their side chains.

Essential and Nonessential Amino Acids

We also classify amino acids based on their nutritional aspects (Table 6.1 “Essential and Nonessential Amino Acids”):

- ***Nonessential amino acids*** are not required in the diet, because the body can synthesize them. They’re still vital to protein synthesis, and they’re still present in food, but because the body can make them, we don’t have to worry about nutritional requirements. There are 11 nonessential amino acids.
- ***Essential amino acids*** can’t be synthesized by the body in sufficient amounts, so they must be obtained in the diet. There are 9 essential amino acids.

Essential	**Nonessential**
Histidine	Alanine
Isoleucine	Arginine*
Leucine	Asparagine
Lysine	Aspartic Acid
Methionine	Cysteine*
Phenylalanine	Glutamic Acid
Threonine	Glutamine

Tryptophan	Glycine*
Valine	Proline*
	Serine
	Tyrosine*
***Conditionally essential**	

Table 6.1. Essential and nonessential amino acids

Sometimes during infancy, growth, and in diseased states, the body cannot synthesize enough of some of the nonessential amino acids and more of them are required in the diet. These types of amino acids are called ***conditionally essential amino acids***.

The nutritional value of a protein is dependent on what amino acids it contains and in what quantities. As we'll discuss later, a food that contains all of the essential amino acids in adequate amounts is called a ***complete protein source***, whereas one that does not is called an ***incomplete protein source***.

The Many Different Types of Proteins

There are over 100,000 different proteins in the human body. Proteins are similar to carbohydrates and lipids in that they are polymers (simple repeating units); however, proteins are much more structurally complex. In contrast to carbohydrates, which have identical repeating units, proteins are made up of amino acids that are different from one another. Different proteins are produced because there are 20 types of naturally occurring amino acids that are combined in unique sequences.

Additionally, proteins come in many different sizes. The hormone insulin, which regulates blood glucose, is composed of only 51 amino acids. On the other hand, collagen, a protein that acts like glue between cells, consists of more than 1,000 amino acids. Titin is the largest known protein. It accounts for the elasticity of muscles and consists of more than 25,000 amino acids!

The huge diversity of proteins is also due to the unending number of amino acid sequences that can be formed. To understand how so many different proteins can be made from only 20 amino acids, think about music. All of the music that exists in the world has been derived from a basic set of seven notes C, D, E, F, G, A, B (with the addition of sharps and flats), and there is a vast array of music all composed of specific sequences from these basic musical notes. Similarly, the 20 amino acids can be linked together in an extraordinary number of sequences. For example, if an amino acid sequence for a protein is 104 amino acids long, the possible combinations of amino acid sequences is equal to 20^{104}, which is 2 followed by 135 zeros!

Building Proteins with Amino Acids

The decoding of genetic information to synthesize a protein is the central foundation of modern biology. The building of a protein consists of a complex series of chemical reactions that can be summarized into three basic steps: transcription, translation, and protein folding.

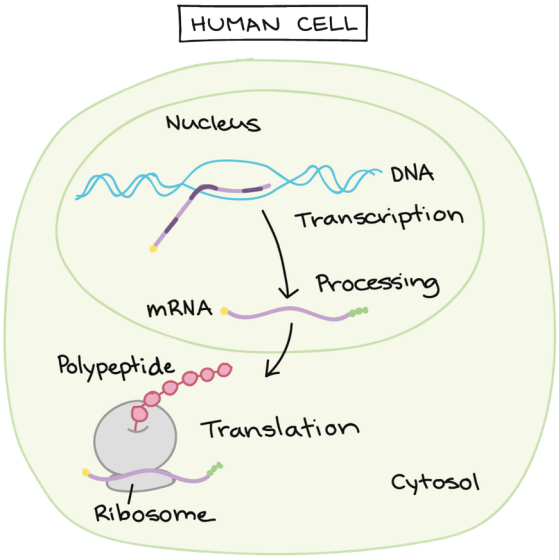


Figure 6.3. Overview of protein synthesis. Protein folding happens after translation.

1. **Transcription** – Deoxyribonucleic acid, or DNA, is the long, double-stranded molecules containing your genome—instructions for making all of the proteins in your body. In the nucleus of the cell, the DNA must be transcribed or copied into the single-stranded messenger ribonucleic acid (mRNA), which carries the genetic instructions into the cell's cytosol for protein synthesis.
2. **Translation** – At the ribosomes in the cell's cytosol, amino acids are linked together in the specific order dictated by the mRNA. Each amino acid is connected to the next amino acid by a special chemical bond called a ***peptide bond*** (Figure 6.4). The peptide bond forms between the carboxylic acid group of one amino acid and the amino group of another, releasing a molecule of water. As amino acids are linked sequentially by peptide bonds, following the specific order dictated by the mRNA, the protein chain, also known as a polypeptide chain, is built (Figure 6.5).

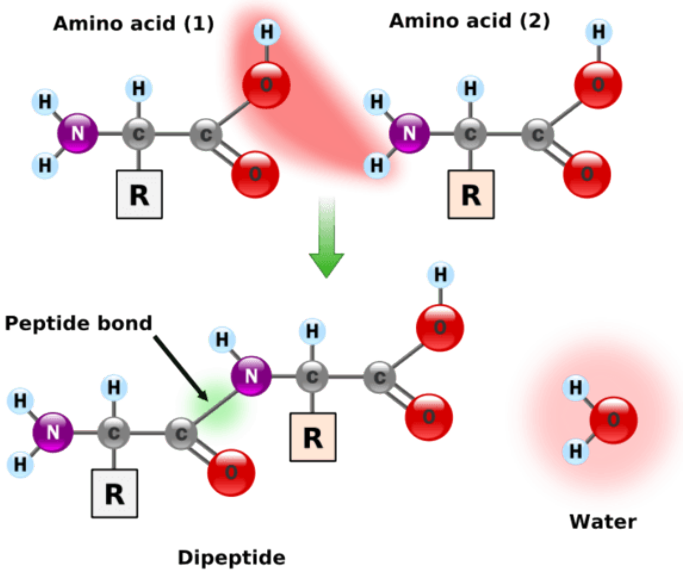


Figure 6.4. Peptide bond formation

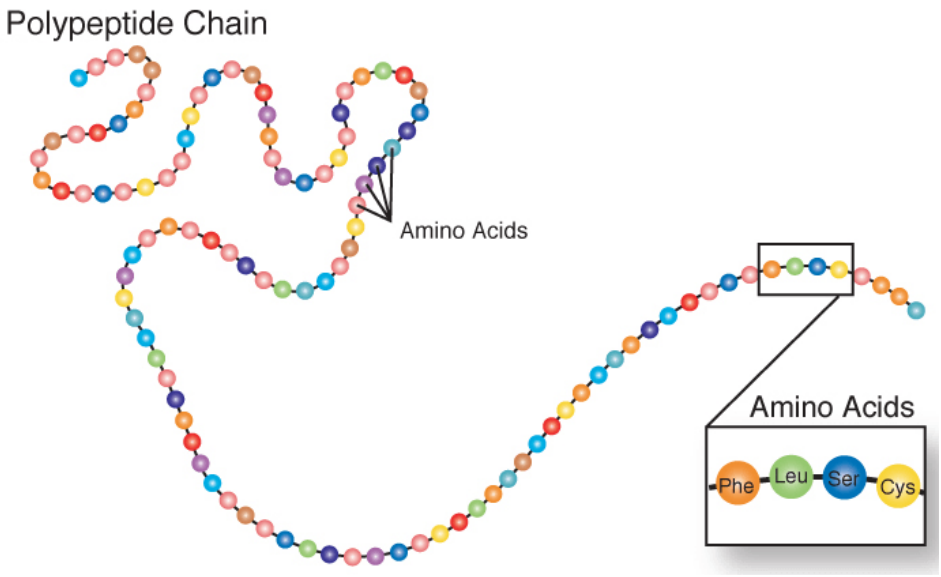


Figure 6. *5. A polypeptide chain*

3. **Protein folding** – The polypeptide chain folds into specific three-dimensional shapes, as described in the next section.

YouTube Video

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VIDEO: "DNA Transcription," by DNA Learning Center, YouTube (March 22, 2010), 1:52 minutes.

YouTube Video

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

View this YouTube Video online

VIDEO: "mRNA Translation," DNA Learning Center, YouTube (March 22, 2010), 2:04 minutes.

Protein Organization

Protein's structure enables it to perform a variety of functions. There are four different structural levels of proteins (Figure 6.6.):

1. **Primary structure** – This is the *one-dimensional polypeptide chain of amino acids*, held together by peptide bonds.
2. **Secondary structure** – The polypeptide chain folds into simple coils (also called helices) and sheets, determined by the chemical interactions between amino acids.
3. **Tertiary structure** – This is the unique three-dimensional shape of a protein, formed as the different side chains of amino acids chemically interact, either repelling or attracting each other. Thus, the sequence of amino acids in a protein directs the

protein to fold into a specific, organized shape.

4. **Quaternary structure** – In some proteins, multiple folded polypeptides called subunits combine to make one larger functional protein. This is called quaternary protein structure. The protein hemoglobin is an example of a protein that has quaternary structure. It is composed of four polypeptides that bond together to form a functional oxygen carrier.

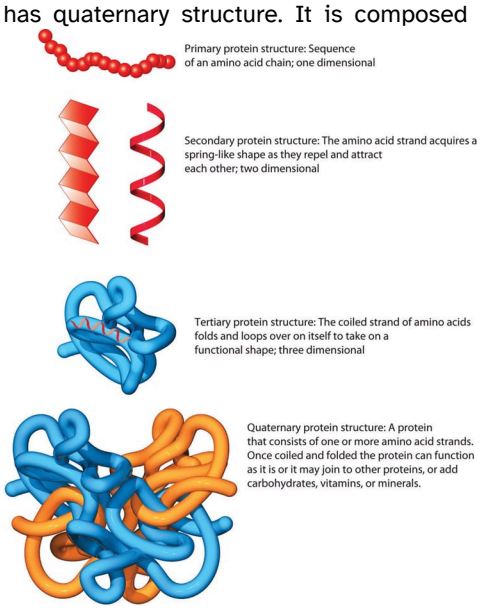


Figure 6.6. A protein has four different structural levels.

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VIDEO: "What is a Protein," by RCSBProteinDataBank, YouTube (September 4, 2016), 2:38 minutes. This video gives an overview of the structure of amino acids, the four different structural levels of protein, and examples of different types of proteins in the body.

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

The specific three-dimensional structure of proteins can be disrupted by changes in their physical environment, causing them to unfold. This is called ***denaturation***, and it results in loss of both structure and function of proteins. Changes in pH (acidic or basic conditions) and exposure to heavy metals, alcohol, and heat can all cause protein denaturation. The proteins in cooked foods are at least partially denatured from the heat of cooking, and denaturation in the stomach is an important part of protein digestion, as we'll discuss later in this unit. We can see everyday examples of denaturation in cooking techniques, like how egg whites become solid and opaque with cooking, and cream becomes fluffy when it's whipped. Both of these are examples of denaturation leading to physical changes in protein structure, and because protein structure determines function, denaturation also causes proteins to lose their function.

VIDEO: "Heat Changes Protein Structure," by Sumanas (2006), 1:22 minutes. You can learn more about denaturation in this video animation.

Shape Determines Function

An important concept with proteins is that **SHAPE determines FUNCTION.** A change in the amino acid sequence will cause a change in protein shape. Each protein in the human body differs in its amino acid sequence and consequently, its shape. The synthesized protein is structured to perform a particular function in a cell. A protein made with an incorrectly placed amino acid may not function properly, and this can sometimes cause disease. An example of this is sickle cell anemia, a genetic disorder. Below is a picture of hemoglobin, a protein with a globular three-dimensional structure. When packed in red blood cells to deliver oxygen, this structure gives red blood cells a donut shape.

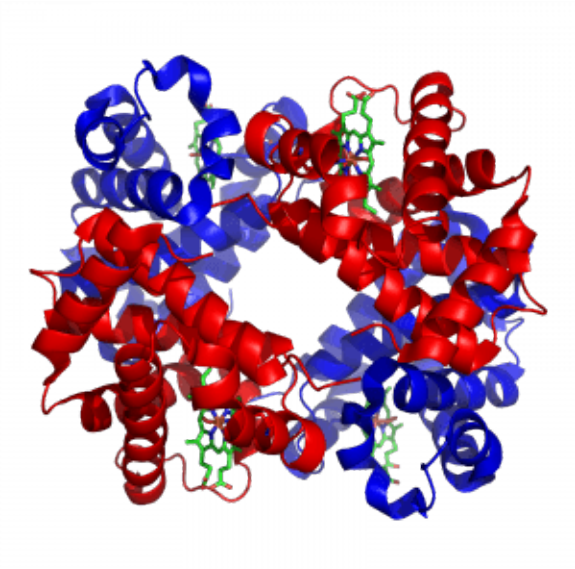


Figure 6.7. Structure of hemoglobin

In people with sickle cell anemia, DNA gives cells the incorrect message when bonding amino acids together to make hemoglobin. The result is crescent-shaped red blood cells that are sticky and do not transport oxygen like normal red blood cells, as illustrated in the figure below.

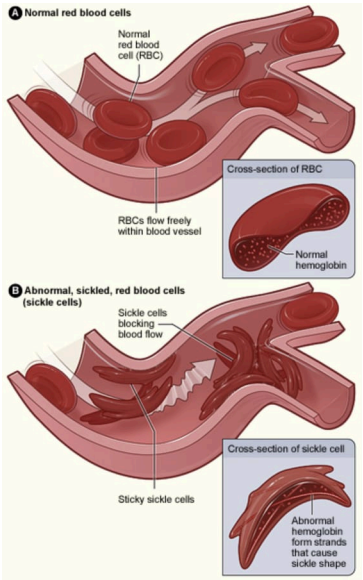


Figure 6.8. Difference in blood cells and blood flow between normal red blood cells and sickle shaped blood cells.

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7.3: Protein Functions

Proteins are the “workhorses” of the body and participate in many bodily functions. As we’ve already discussed, proteins come in all sizes and shapes, and each is specifically structured for its particular function. This page describes some of the important functions of proteins. As you read through them, keep in mind that synthesis of all of these different proteins requires adequate amounts of amino acids. As you can imagine, consuming a diet that is deficient in protein and essential amino acids can impair many of the body’s functions. (More on that later in the unit.)

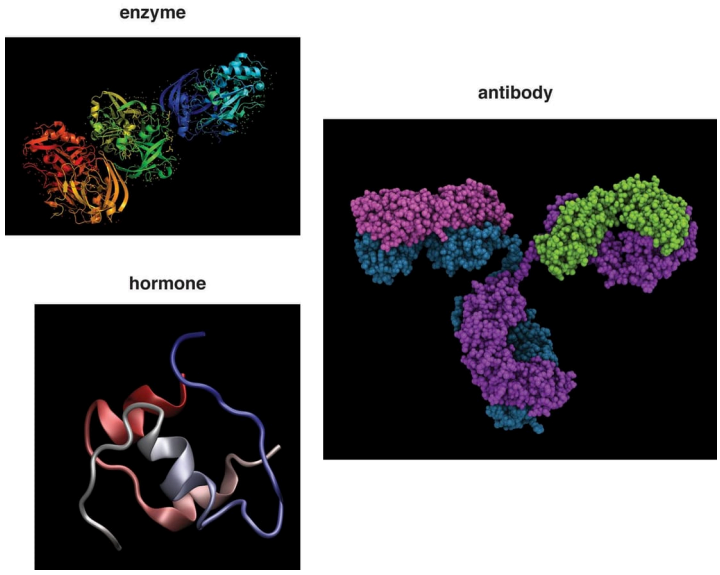


Figure 6.9. Examples of proteins with different functions, sizes, and shapes.

Major types and functions of proteins are summarized in the table below, and the subsequent sections of this page give more detail on each of them.

Protein Types and Functions		
Type	**Examples**	**Functions**
Structure	Actin, myosin, collagen, elastin, keratin	Give tissues (bone, tendons, ligaments, cartilage, skin, muscles) strength and structure
Enzymes	Amylase, lipase, pepsin, lactase	Digest macronutrients into smaller monomers that can be absorbed; performs steps in metabolic pathways to allow for nutrient utilization
Hormones	Insulin, glucagon, thyroxine	Chemical messengers that travel in blood and coordinate processes around the body

Fluid and acid-base balance	Albumin, hemoglobin	Maintains appropriate balance of fluids and pH in different body compartments
Transport	Hemoglobin, albumin, protein channels, carrier proteins	Carry substances around the body in the blood or lymph; help molecules cross cell membranes
Defense	Collagen, lysozyme, antibodies	Protect the body from foreign pathogens

Table 6.2. Protein types and functions

Structure

More than one hundred different structural proteins have been discovered in the human body, but the most abundant by far is ***collagen***, which makes up about 6 percent of total body weight. Collagen makes up 30 percent of bone tissue and comprises large amounts of tendons, ligaments, cartilage, skin, and muscle. Collagen is a strong, fibrous protein made up of mostly glycine and proline amino acids. Within its quaternary structure, three protein strands twist around each other like a rope and then these collagen ropes overlap with others.

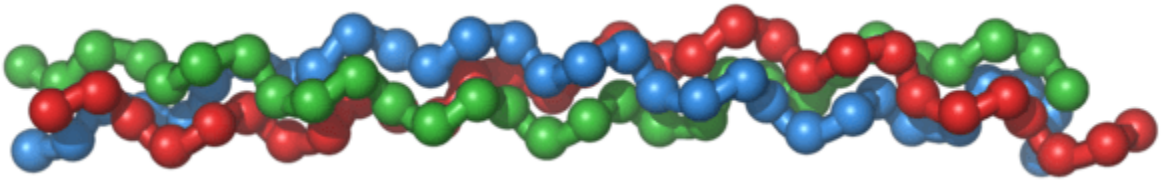


Figure 6.10. Triple-helix structure of collagen

This highly ordered structure is even stronger than steel fibers of the same size. Collagen makes bones strong but flexible. Collagen fibers in the skin's dermis provide it with structure, and the accompanying ***elastin*** protein fibrils make it flexible. Pinch the skin on your hand and then let go; the collagen and elastin proteins in skin allow it to go back to its original shape. Smooth-muscle cells that secrete collagen and elastin proteins surround blood vessels, providing the vessels with structure and the ability to stretch back after blood is pumped through them. Another strong, fibrous protein is ***keratin***, an important component of skin, hair, and nails.

Enzymes

Enzymes are proteins that conduct specific chemical reactions. An enzyme's job is to provide a site for a chemical reaction and to lower the amount of energy and time it takes for that chemical reaction to happen (this is known as "catalysis"). On average, more than 100 chemical reactions occur in cells every single second, and most of them require enzymes. The liver alone contains over 1,000 enzyme systems. Enzymes are specific and will use only particular substrates that fit into their active site, similar to the way a lock can be opened only with a specific key. 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.

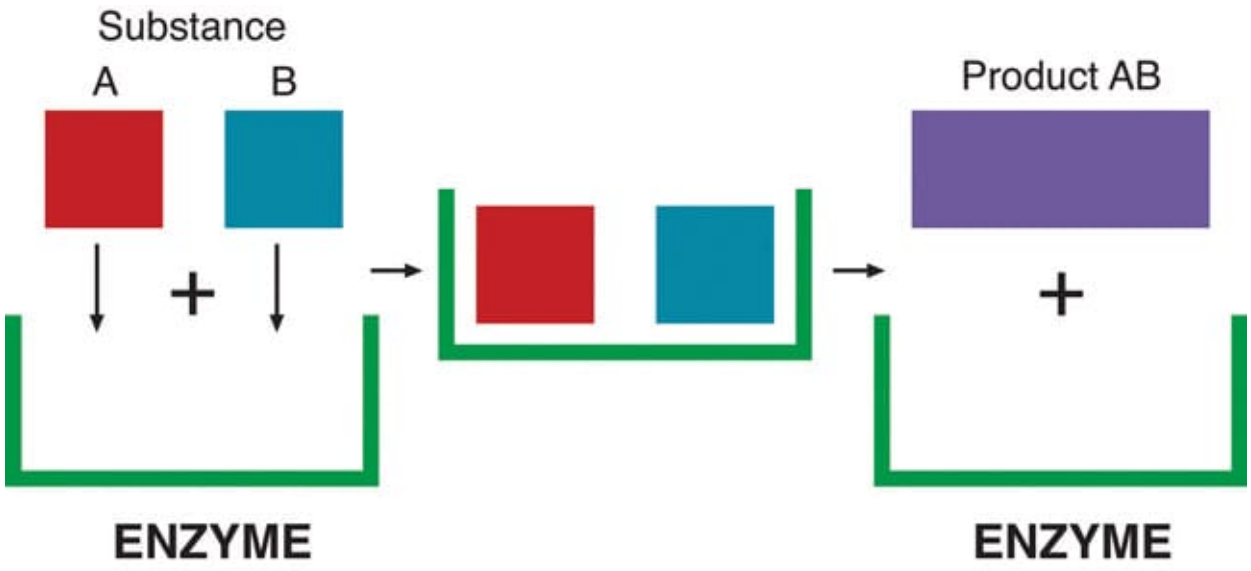


Figure 6.11. Enzymes are proteins. An enzyme's job is to provide a site for substances to chemically react and form a product, and decrease the amount of energy and time it takes for this to happen.

YouTube Video

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VIDEO: "Enzymes with the Amoeba Sisters," by the Amoeba Sisters, YouTube (August 28, 2016), 0:47 minutes. This video demonstrates the action of enzymes.

Hormones

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

Fluid and Acid-Base Balance

Adequate protein intake enables the basic biological processes of the body to maintain homeostasis (constant or stable conditions) in a changing environment. One aspect of this is fluid balance, keeping water distributed properly in the different compartments of the body. If too much water suddenly moves from the blood into a tissue, the results are swelling and, potentially, cell death. Water always flows from an area of high concentration to an area of low concentration. As a result, water moves toward areas that have higher concentrations of other solutes, such as proteins and glucose. To keep the water evenly distributed between blood and cells, proteins continuously circulate at high concentrations in the blood. The most abundant protein in blood is the butterfly-shaped protein known as ***albumin***. The presence of albumin 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 homeostasis.

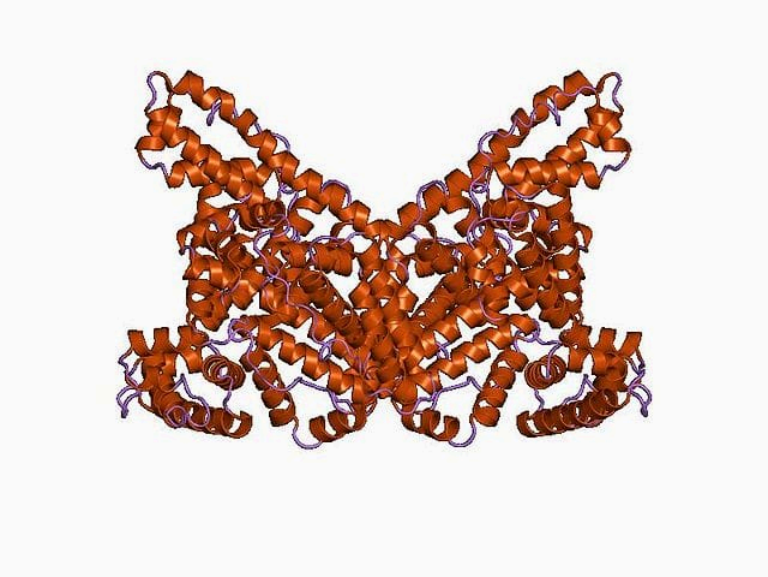


Figure 6.12. The butterfly-shaped protein, albumin, has many functions in the body including maintaining fluid and acid-base balance and transporting molecules.

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

Transport

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

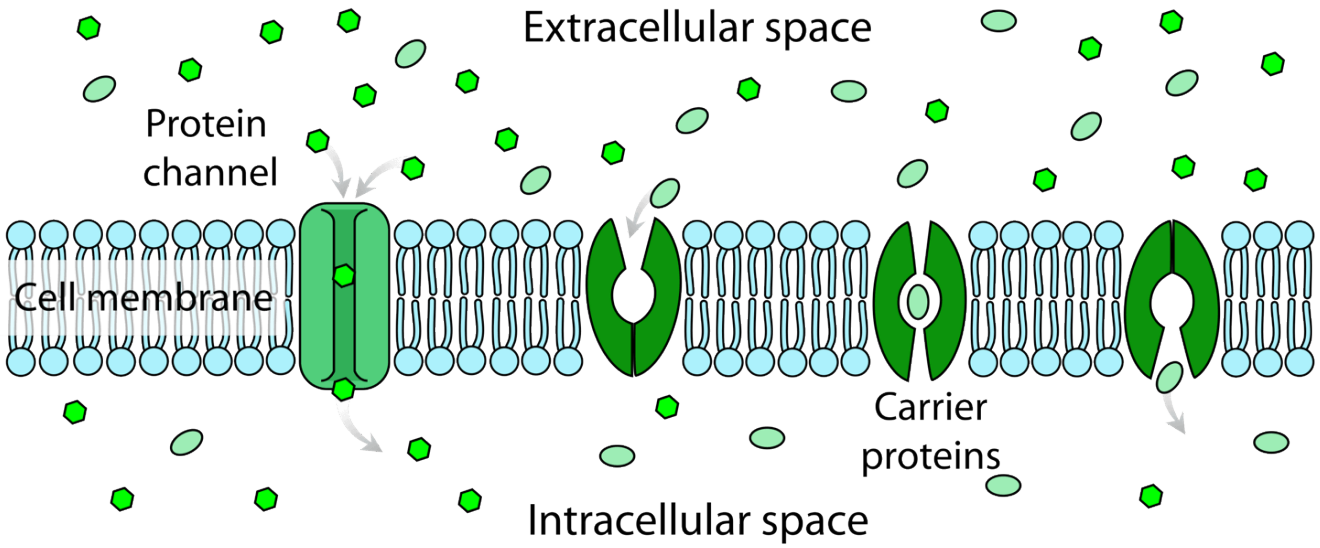


Figure 6.13. Molecules move in and out of cells through transport proteins, which are either channels or carriers.

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VIDEO: "The Sodium-Potassium Pump," by RicochetScience, YouTube (May 23, 2016), 2:26 minutes. This tutorial describes how the sodium-potassium pump uses active transport to move sodium ions (Na+) out of a cell, and potassium ions (K+) into a cell.

Immunity

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

YouTube Video

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VIDEO: "Specific Immunity, Antibodies," by Carpe Noctum, YouTube (December 11, 2007), 1 minute. Watch this video to observe how antibodies protect against foreign intruders.

Energy Production

Some of the amino acids in proteins can be disassembled and used to make energy. Only about 10 percent of dietary proteins are catabolized each day to make cellular energy. The liver is able to break down amino acids to the carbon skeleton, which can then be fed into the citric acid or Krebs cycle. This is similar to the way that glucose is used to make ATP. If a person's diet does not contain enough carbohydrates and fats, their body will use more amino acids to make energy, which can compromise the synthesis of new proteins and destroy muscle proteins if calorie intake is also low.

Not only can amino acids be used for energy directly, but they can also be used to synthesize glucose through gluconeogenesis. Alternatively, if a person is consuming a high protein diet and eating more calories than their body needs, the extra amino acids will be broken down and transformed into fat. **Unlike carbohydrate and fat, protein does not have a specialized storage system to be used later for energy.**

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7.4: Protein in Foods and Dietary Recommendations

In this section, we'll discuss how to determine how much protein you need and your many choices in designing an optimal diet with high-quality protein sources.

How Much Dietary Protein Does a Person Need?

Because our bodies are so efficient at recycling amino acids, protein needs are not as high as carbohydrate and fat needs. **The Recommended Dietary Allowance (RDA) for a sedentary adult is 0.8 g per kg body weight per day**. This would mean that a 165 pound man, and a 143 pound woman would need 60 g and 52 g of protein per day, respectively. **The Acceptable Macronutrient Distribution Range (AMDR) for protein for adults is 10% to 35% of total energy intake**. A Tolerable Upper Intake Limit for protein has not been set, but it is recommended that you not exceed the upper end of the AMDR.

Protein needs are higher for the following populations:

- growing children and adolescents
- women who are pregnant (they're using protein to help grow a fetus)
- lactating women (breast milk has protein in it for the baby's nutrition, so mothers need more protein to synthesize that milk)
- athletes

The Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine recommend 1.2 to 2.0 grams of protein per kilogram of body weight per day for athletes, depending on the type of training.[1] Higher intakes may be needed for short periods during intensified training or with reduced energy intake.

Nitrogen Balance to Determine Protein Needs

The appropriate amount of protein in a person's diet is that which maintains a balance between what is taken in and what is used. The RDAs for protein were determined by assessing ***nitrogen balance***. Nitrogen is one of the four basic elements contained in all amino acids. When amino acids are broken down, nitrogen is released. Most nitrogen is excreted as urea in urine, but some urea is also contained in feces. Nitrogen is 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 by the body, measured as the amount of nitrogen lost from the body. The Institute Of Medicine used data from multiple studies that determined nitrogen balance in people of different age groups to calculate the RDA for protein.

- **Nitrogen Balance**– A person is said to be in nitrogen balance when the nitrogen consumed equals the amount of nitrogen excreted. Most healthy adults are in nitrogen balance. If more protein is consumed than needed, this extra protein is used for energy, and the nitrogen waste that results is excreted. The lowest amount of protein a person can consume and still remain in nitrogen balance represents that person's minimum protein requirement.

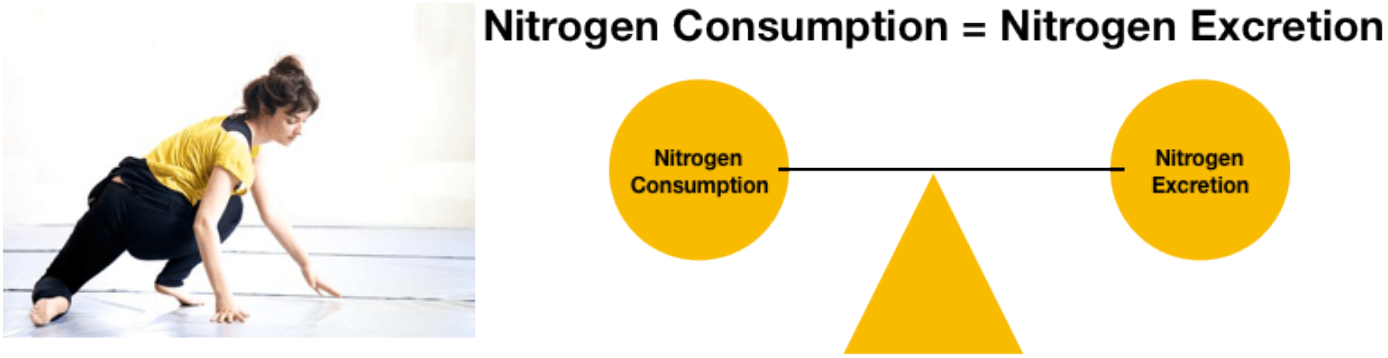


Figure 6.14. People are in nitrogen balance when they excrete as much nitrogen as they consume.

- **Negative Nitrogen Balance**– A person is in negative nitrogen balance when the amount of excreted nitrogen is greater than

that consumed, meaning that the body is breaking down more protein to meet its demands. This state of imbalance can occur in people who have certain diseases, such as cancer or muscular dystrophy. Someone who is eating a low-protein diet may also be in negative nitrogen balance as they are taking in less protein than they actually need.

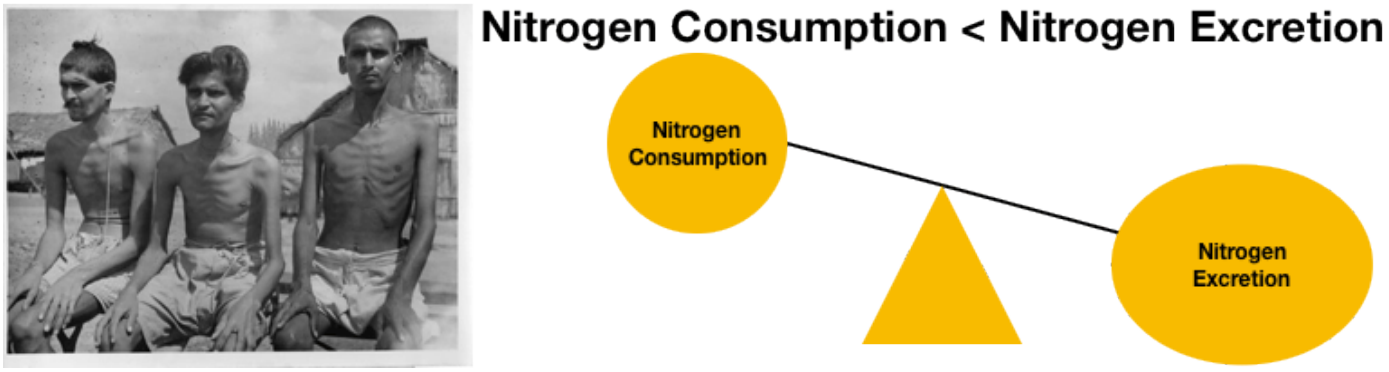


Figure 6.15. People are in negative nitrogen balance when they excrete more nitrogen than they consume, usually because they are not eating enough protein to meet their needs.

- **Positive Nitrogen Balance-** A person is in positive nitrogen balance when a person excretes less nitrogen than what is taken in by the diet, such as during pregnancy or growth in childhood. At these times the body requires more protein to build new tissues, so more of what gets consumed gets used up and less nitrogen is excreted. A person healing from a severe wound may also be in positive nitrogen balance because protein is being used up to repair tissues.

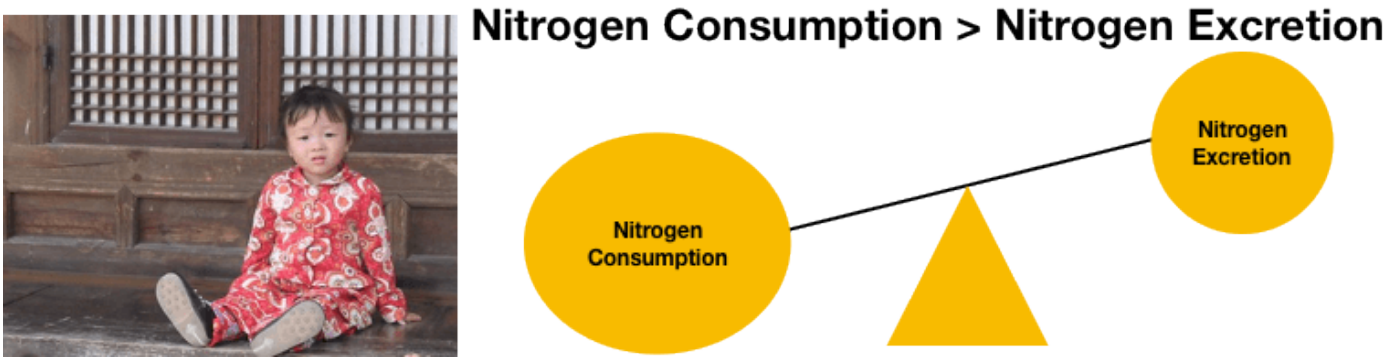


Figure 6.16. People are in positive nitrogen balance when they excrete less nitrogen than they consume, because they are using protein to actively build new tissue.

Dietary Sources of Protein

Although meat is the typical food that comes to mind when thinking of protein, many other foods are rich in protein as well, including dairy products, eggs, beans, whole grains, and nuts. Table 6.3 lists the grams of protein in a standard serving for a variety of animal and plant foods.

Animal Sources	**Grams of Protein per Standard Serving**
Egg White	3 g per 1 large white
Whole Egg	6 g per 1 large egg

Cheddar Cheese	7 g per 1 oz. (30 g)
Milk, 1%	8 g per 1 cup (8 fl oz)
Yogurt	11 g per 8 oz
Greek Yogurt	22 g per 8 oz
Cottage Cheese	15 g per ½ cup
Hamburger	30 g per 4 oz
Chicken	35 g per 4 oz
Tuna	40 g per 6 oz can
Plant Sources	**Grams of Protein per Standard Serving**
Almonds, dried	6 g per 1 oz
Almond milk	1 g per cup (8 fl oz)
Soy milk	8g per cup (8 fl oz)
Peanut butter	4 g per 1 tbsp
Hummus	8 g per ½ cup
Refried beans	6 g per ½ cup
Lentil soup	11 g per 10.5 oz
Tofu, extra firm	11 g per 3.5 oz

Enriched wheat bread	1 g per slice (45 g)
Whole Grain Bread	5g per slice (45 g)
Grape Nuts	7 g per ½ cup

Table 6.3. Protein in common foods [2]

Notice in the table above that whole foods contain more protein than refined foods. When foods are refined—for example, going from a whole almond to almond milk or whole grain to refined grain—protein is lost in that processing. **Very refined foods like oil and sugar contain no protein.**

The USDA provides some tips for choosing your dietary protein sources. The overall suggestion is to eat a variety of protein-rich foods to benefit health. Examples include:

- Lean meats, such as round steaks, top sirloin, extra lean ground beef, pork loin, and skinless chicken.
- 8 ounces of cooked seafood every week (typically as two 4-ounce servings).
- Choosing to eat beans, peas, or soy products as a main dish. For example, chili with kidney and pinto beans, hummus on pita bread, and black bean enchiladas.
- Enjoy nuts in a variety of ways. Put them on a salad, in a stir-fry, or use them as a topping for steamed vegetables in place of meat or cheese.

Protein Quality

While protein is contained in a wide variety of foods, it differs in quality. High-quality ***complete proteins*** contain all nine essential amino acids. Lower-quality ***incomplete proteins*** do not contain all nine essential amino acids in proportions needed to support growth and health.

Foods that are complete protein sources include animal foods such as milk, cheese, eggs, fish, poultry, and meat. A few plant foods also are complete proteins, such as soy (soybeans, soy milk, tofu, tempeh) and quinoa.

Most plant-based foods are deficient in at least one essential amino acid and therefore are incomplete protein sources.



For example, grains are usually deficient in the amino acid lysine, and legumes are low in methionine and tryptophan. Because grains and legumes are not deficient in the same amino acids, they can complement each other in a diet. When consumed in tandem, they contain all nine essential amino acids at adequate levels, so they are called ***complementary proteins***. Some examples of complementary protein foods are given in Table 6.4. ***Mutual supplementation*** is another term used when combining two or more incomplete protein sources to make a complete protein. 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. Most people eat complementary proteins without thinking about it, because they go well together. Think of a peanut butter sandwich and beans and rice; these are examples of complementary proteins. So long as you eat a variety of foods, you don't need to worry much about incomplete protein foods. They may be called "lower quality" in terms of protein, but they're still great choices, as long as they're not the only foods you eat!

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

Table 6.4. Complementary protein sources

The second component of protein quality is digestibility, as not all protein sources are equally digested. **In general, animal-based proteins are more fully digested than plant-based proteins,** because some proteins are contained in the plant's fibrous cell walls and these pass through the digestive tract unabsorbed by the body. Animal proteins tend to be 95 percent or more digestible; soy is estimated at 91 percent; and many grains are around 85 to 88 percent digestible.[3]

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References:

- [1]Thomas, D. T., Erdman, K. A., & Burke, L. M. (2016). Position of Dietitians of Canada, the Academy of Nutrition and Dietetics and the American College of Sports Medicine: Nutrition and Athletic Performance. *Journal of the Academy of Nutrition and Dietetics*, *116(3),* 501-528.
- [2]USDA National Nutrient Database for Standard Reference, December 2018.
- [3]Tome, D. (2012). Criteria and markers for protein quality assessment – a review. *British Journal of Nutrition* 108, S222–S229.

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7.5: Protein Digestion and Absorption

When you eat food, the body's digestive system breaks down dietary protein into 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 path that proteins take down the gastrointestinal tract and into the circulatory system.

Eggs are a good dietary source of protein and will be used as our example as we discuss the processes of digestion and absorption of protein. One egg, whether raw, hard-boiled, scrambled, or fried, supplies about six grams of protein.

In the image below, follow the numbers to see what happens to the protein in our egg at each site of digestion.

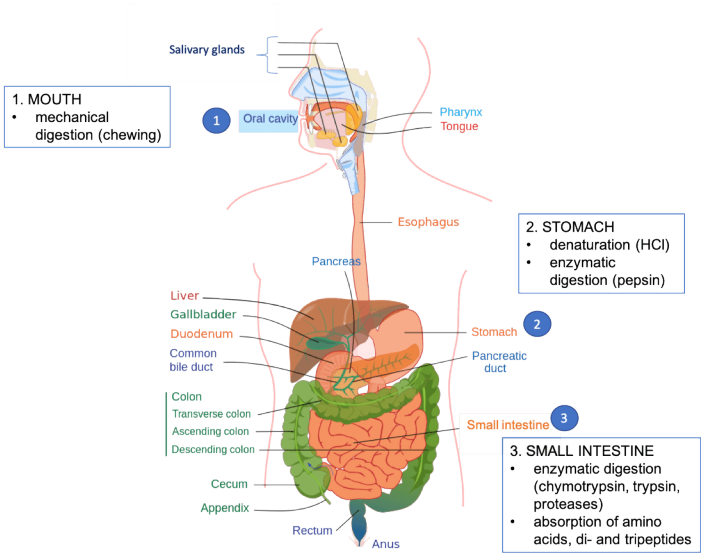


Fig. 6.17. Protein digestion in the human GI tract.

1 – Protein digestion in the mouth

Unless you are eating it raw, the first step in digesting an egg (or any other solid food) is chewing. The teeth begin the **mechanical breakdown** of large egg pieces into smaller pieces that can be swallowed. The salivary glands secrete saliva to aid swallowing and the passage of the partially mashed egg through the esophagus.

2 – Protein digestion in the stomach

The mashed egg pieces enter the stomach from the esophagus. As illustrated in the image below, both mechanical and chemical digestion take place in the stomach. The stomach releases gastric juices containing ***hydrochloric acid*** and the enzyme, ***pepsin***, which initiate the chemical digestion of protein. Muscular contractions, called peristalsis, also aid in digestion. The powerful stomach contractions churn the partially digested protein into a more uniform mixture, which is called chyme.

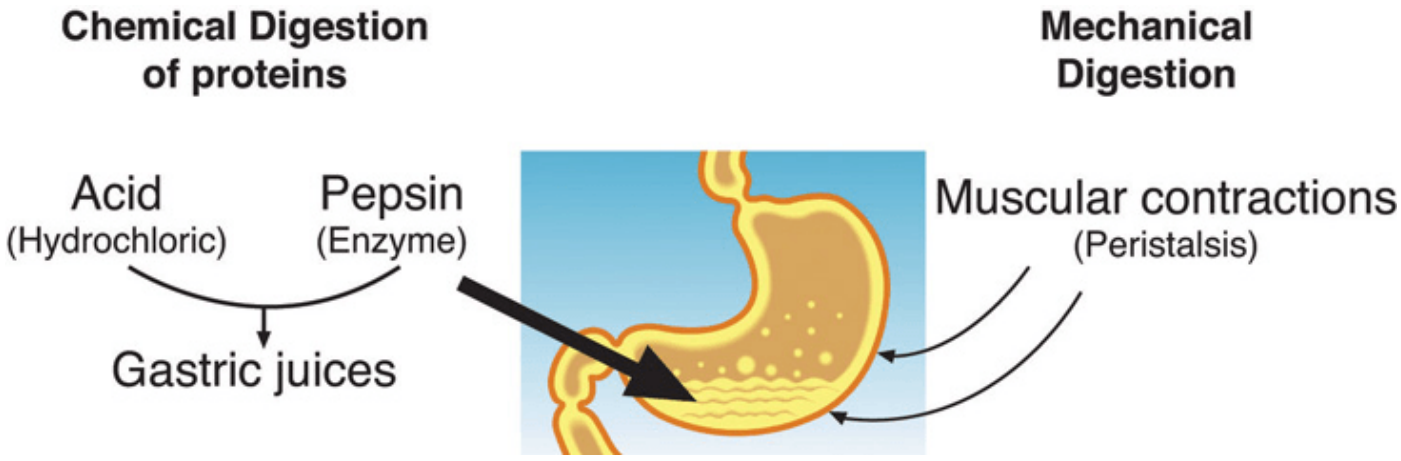


Fig. 6.18. Protein digestion in the stomach

Because of the hydrochloric acid in the stomach, it has a very low pH of 1.5-3.5. **The acidity of the stomach causes food proteins to denature, unfolding their three-dimensional structure** to reveal just the polypeptide chain. This is the first step of chemical digestion of proteins. Recall that the three-dimensional structure of a protein is essential to its function, so **denaturation in the stomach also destroys protein function**. (This is why a protein such as insulin can't be taken as an oral medication. Its function is destroyed in the digestive tract, first by denaturation and then further by enzymatic digestion. Instead, it has to be injected so that it is absorbed intact into the bloodstream.)

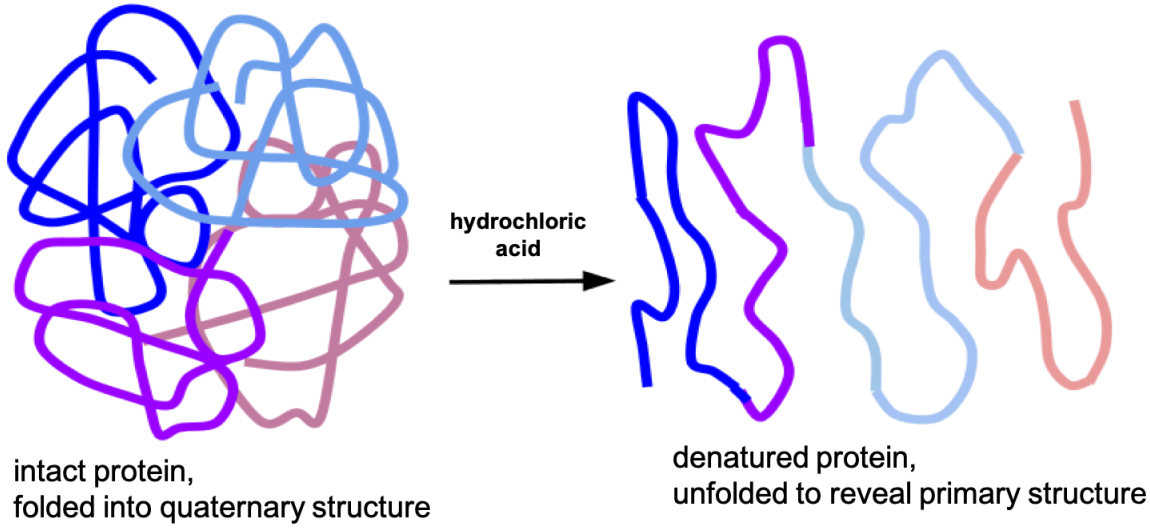


Fig. 6.19. In the stomach, proteins are denatured because of the acidity of hydrochloric acid.

Once proteins are denatured in the stomach, the peptide bonds linking amino acids together are more accessible for enzymatic digestion. That process is started by ***pepsin***, an enzyme that is secreted by the cells that line the stomach and is activated by hydrochloric acid. Pepsin begins breaking peptide bonds, creating shorter polypeptides.

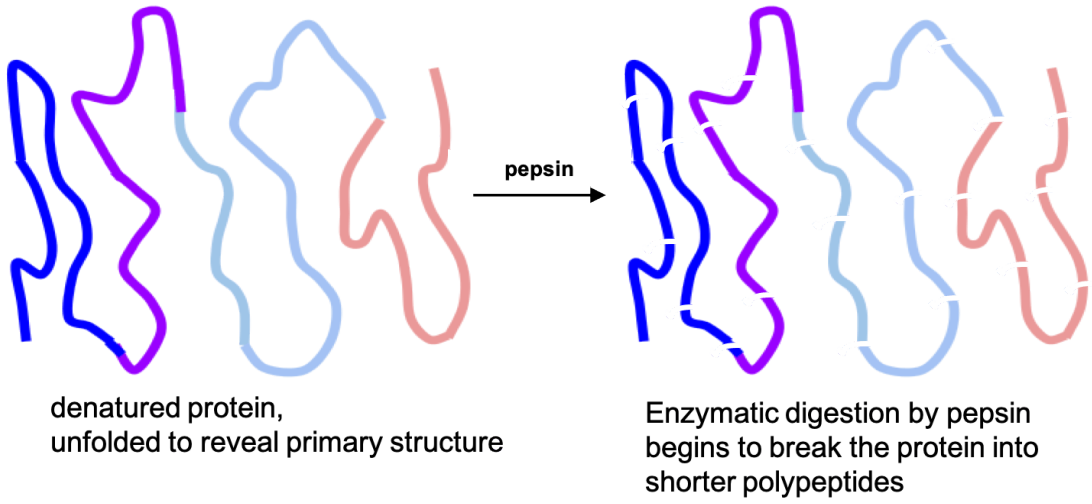


Fig. 6.20. Enzymatic digestion of proteins begins in the stomach with the action of the enzyme pepsin.

Proteins are large globular molecules, and their chemical breakdown requires time and mixing. 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.

3 – Protein digestion and absorption in the small intestine

The chyme leaves the stomach and enters the small intestine, where the majority of protein digestion occurs. The pancreas secretes digestive juices into the small intestine, and these contain more enzymes to further break down polypeptides.

The two major pancreatic enzymes that digest proteins in the small intestine are ***chymotrypsin*** and ***trypsin***. Trypsin activates other protein-digesting enzymes called ***proteases***, and together, **these enzymes break proteins down to tripeptides, dipeptides, and individual amino acids.** The cells that line the small intestine release additional enzymes that also contribute to the enzymatic digestion of polypeptides.

Tripeptides, dipeptides, and single amino acids enter the enterocytes of the small intestine using active transport systems, which require ATP. **Once inside, the tripeptides and dipeptides are all broken down to single amino acids, which are absorbed into the bloodstream.** There are several different types of transport systems to accommodate different types of amino acids. Amino acids with structural similarities end up competing to use these transporters. That's not a problem if your protein is coming from food, because it naturally contains a mix of amino acids. However, if you take high doses of amino acid supplements, those could theoretically interfere with absorption of other amino acids.

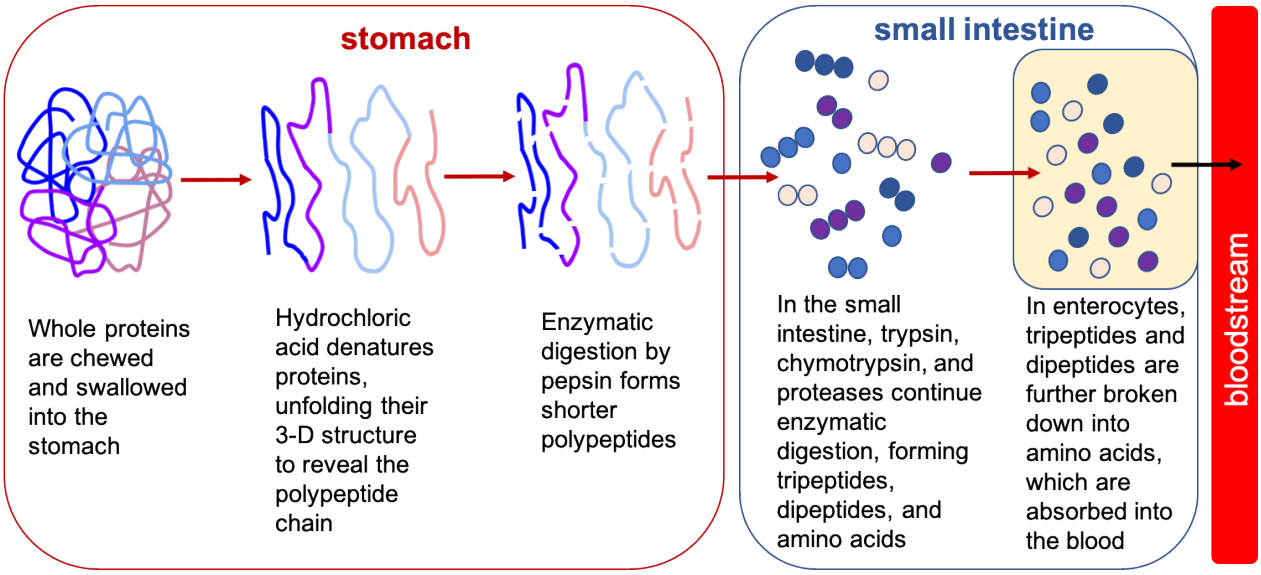


Fig. 6.21. Summary of protein digestion. Note that the lines representing polypeptide chains in the stomach consist of strings of amino acids connected by peptide bonds, even though the individual amino acids aren't shown in this simplified representation.

Proteins that aren't fully digested in the small intestine pass into the large intestine and are eventually excreted in the feces. Recall from the last page that plant-based proteins are a bit less digestible than animal proteins, because some proteins are bound in plant cell walls.

What happens to absorbed amino acids?

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. Dietary amino acids then become part of the body's amino acid pool.

Assuming the body has enough glucose and other sources of energy, those amino acids will be used in one of the following ways:

- Protein synthesis in cells around the body
- Making nonessential amino acids needed for protein synthesis
- Making other nitrogen-containing compounds
- Rearranged and stored as fat (there is no storage form of protein)

If there is not enough glucose or energy available, amino acids can also be used in one of these ways:

- Rearranged into glucose for fuel for the brain and red blood cells
- Metabolized as fuel, for an immediate source of ATP

In order to use amino acids to make ATP, glucose, or fat, the nitrogen first has to be removed in a process called ***deamination***, which occurs in the liver and kidneys. The nitrogen is initially released as ammonia, and because ammonia is toxic, the liver transforms it into urea. Urea is then transported to the kidneys and excreted in the urine. Urea is a molecule that contains two nitrogens and is highly soluble in water. This makes it ideal for transporting excess nitrogen out of the body.

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

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

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

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




Fig. 6.22. Diverse human cultures have survived on different levels of dietary protein. The photo on the left shows Inuit families sharing frozen, aged walrus meat. Their traditional diet is very dependent on meat and high in both protein and fat. On the right is a traditional vegetarian meal in India, high in carbohydrates but still providing adequate levels of protein.

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

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

Health Consequences of Protein Deficiency

In low-income countries

Severe protein deficiency, once called protein-energy malnutrition (PEM) and historically described as kwashiorkor or marasmus, refers to inadequate protein and energy intake leading to growth failure, wasting, and other serious health effects in children. Although it was historically thought to be a major cause of child mortality, particularly in low-income countries, global health nutrition has evolved, and the language we use to describe malnutrition has changed. The syndromes once commonly referred to as **Kwashiorkor** and **Marasmus** — terms familiar to many from older textbooks and media — are no longer used in UNICEF's *State of the World's Children* reports or in most contemporary public health assessments. These terms described severe protein deficiency, either with edema (Kwashiorkor) or extreme wasting (Marasmus), but today, child malnutrition is assessed more holistically, recognizing that deficits often involve Calories, protein, micronutrients, and essential fatty acids.

Historically, **Kwashiorkor** described children, often recently weaned, who appeared swollen due to fluid imbalance, poor growth, liver dysfunction, and low muscle mass. The name comes from a Ghanaian word meaning "rejected one," reflecting that it often occurred when a child was displaced from breastfeeding to a low-protein, low-nutrient diet. While these historical descriptions are still valid for understanding past cases, today such children would be categorized as having **Severe Acute Malnutrition (SAM)**, which includes not only protein deficiency but also other nutrient deficiencies that contribute to swelling, poor growth,

and vulnerability to infection.

Similarly, **Marasmus**, meaning “starvation” in Greek, described children who were extremely emaciated due to both inadequate protein and insufficient calories. Children with this condition could weigh up to 80 percent less than a healthy child of the same age and were highly susceptible to infections and fatigue. In contemporary practice, such children are identified as experiencing **wasting**, a condition defined by low weight-for-height that signals acute malnutrition. Wasting is a key indicator used to classify **Severe Acute Malnutrition (SAM)** when severe, or **Moderate Acute Malnutrition (MAM)** when less severe, and reflects not only insufficient calories and protein but often deficits in micronutrients and essential fatty acids critical for growth and cognitive development. Historically, both Marasmus and the edema-associated form of malnutrition once called **Kwashiorkor** would today be captured under the broader wasting framework, allowing health programs to more systematically assess and treat children with acute malnutrition regardless of whether swelling or extreme emaciation is present.

In today's parlance, for instance, the 2023 UNICEF report on child malnutrition indicates that in 2022, approximately **45 million children under five** (6.8% of the global under-five population) were affected by wasting, a severe form of malnutrition characterized by low weight-for-height. The report also notes that **148.1 million children** (22.3%) were stunted, characterized by low height-for-age, which is a condition resulting from chronic undernutrition — especially in key micronutrients such as zinc — leading to impaired growth.

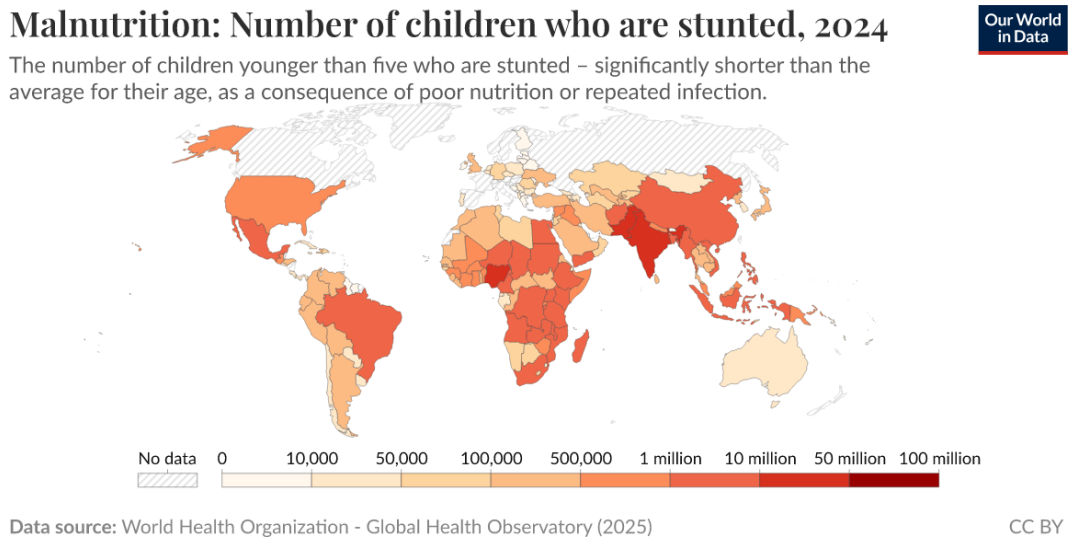
Recognizing the shift in terminology is not meant to dismiss the historical importance of Kwashiorkor and Marasmus. Rather, it offers an opportunity to understand how global health nutrition has advanced: from a focus on single nutrient deficiencies to a more comprehensive approach that accounts for energy, protein, micronutrients, and other essential dietary components. Today, interventions aim to prevent **child stunting and wasting** by addressing the full spectrum of nutritional needs, providing a more accurate and actionable framework for improving child health in low-income countries.

Two photos show children suffering from protein energy malnutrition. On the left is a child with kwashiorkor, showing the hallmark swollen belly. On the right is a child with marasmus, showing very thin limbs and visible ribs, no swollen belly.

Figure 6.23. The photo on the left shows a child suffering from what was historically called ***kwashiorkor*** *(note the swollen belly) in the late 1960s in a Nigerian relief camp during the Nigerian-Biafran War. The photo on the right shows an Indian child suffering from what was historically called* ***marasmus*** .

While conditions like stunting and wasting are visible indicators of malnutrition, the majority of child malnutrition today is less apparent — often termed “hidden hunger.” This form of malnutrition stems from deficiencies in essential micronutrients such as iron, vitamin A, and zinc, as well as essential fatty acids. These deficiencies can impair cognitive development, weaken immune systems, and hinder physical growth, even in children who appear well-nourished.

According to the latest data from UNICEF, approximately **150.2 million children under five** remain stunted as of 2024, a slight decline from 180.4 million in 2012. However, this progress is insufficient to meet the 2030 global nutrition targets. Moreover, the prevalence of wasting has remained largely unchanged, affecting **6.6% of children** globally.



Addressing hidden hunger requires a comprehensive approach that goes beyond protein and energy intake. It involves ensuring access to a diverse and balanced diet, fortifying staple foods with essential nutrients, and implementing public health interventions that target both the immediate and underlying causes of malnutrition. Recognizing and addressing hidden hunger is crucial for the survival, growth, and development of children worldwide.

In the United States

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

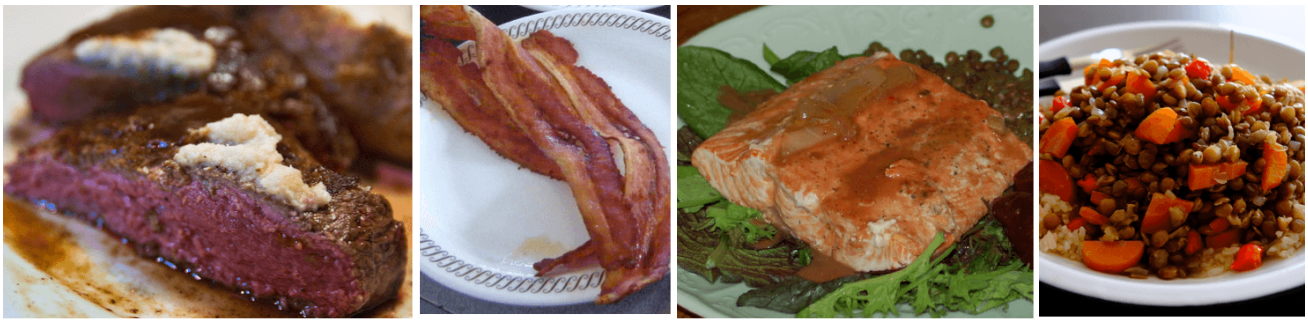
Low protein intake is also a concern for the elderly in the U.S. The same 2018 study found that among those 71 years and older, 19 percent of women and 13 percent of men consume less protein than the RDA.[2] This is a particular concern in this age group, as loss of muscle is accelerated with aging,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

Health Consequences of Too Much Protein in the Diet

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

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

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



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

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

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

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

Fig. 6.24. Compare several different "protein packages." The steak and bacon provide protein but also large amounts of saturated fat and sodium. Salmon provides as much protein as the steak but with less saturated fat and more polyunsaturated fats. Lentils are a good source of protein, are low in fat, and are a great source of fiber.

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

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

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

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7.7: Protein Food Choices and Sustainability

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

Animal Agriculture and Resource Use

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



Fig. 6.25. Protein Scorecard from the World Resources Institute. Source: https://www.wri.org/resources/data-v...tein-scorecard

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

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

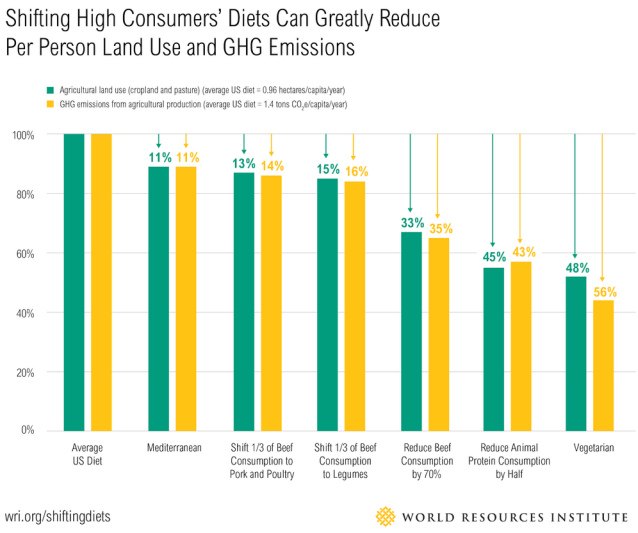


Fig. 6.26. Shifting High Consumers' Diets Can Greatly Reduce Per Person Land Use and GHG Emissions from the World Resources Institute. Source: https://www.wri.org/resources/charts...nt-based-foods

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

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

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

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

The EAT-Lancet Commission and the Planetary Health Diet

The EAT-Lancet Commission has proposed a global reference diet that emphasizes a shift toward more plant-based protein sources as a strategy to simultaneously support human health and environmental sustainability. This framework encourages reducing reliance on animal-derived proteins — especially red and processed meats — and increasing consumption of legumes, nuts, seeds, and whole grains. From a nutrition standpoint, these plant proteins are rich in fiber, phytonutrients, and essential micronutrients, while also being lower in saturated fat, making them beneficial for preventing chronic diseases such as heart disease, type 2 diabetes, and certain cancers. Environmentally, plant-based protein sources generally require fewer natural resources — such as land, water, and energy — and generate significantly lower greenhouse gas emissions than animal agriculture. In this way, aligning dietary protein choices with the EAT-Lancet recommendations presents a win-win scenario: promoting optimal human health while reducing agriculture's ecological footprint.

A daily meal plan based on the **EAT-Lancet Planetary Health Diet** emphasizes **mostly plant-based foods**, with modest amounts of **animal-source foods**, creating a pattern that supports both human health and environmental sustainability. Here's what a typical day might look like:

Breakfast

- **Oatmeal** made with water or a plant-based milk, topped with **fresh fruit**, **a handful of nuts**, and a drizzle of **unsweetened nut butter**
- **Black coffee or tea**, with minimal or no sugar

Lunch

- **Whole grain bowl** with **quinoa or brown rice**, **chickpeas or lentils**, **roasted seasonal vegetables** (e.g., carrots, zucchini, broccoli)
- A side of **leafy greens** dressed with **olive oil, lemon, and seeds**
- **Fruit** for dessert, such as an apple or a few slices of melon

Snack

- **Hummus** with **raw vegetables** (carrots, cucumber, bell pepper) or a small handful of **mixed nuts**

Dinner

- **Stir-fry** with **tofu or tempeh**, a variety of **colorful vegetables**, and a **small portion of whole grains** like farro or barley
- Optional: a small portion (e.g., 1–2 ounces) of **fish or poultry** a few times per week, but not daily
- **Herbal tea** after dinner

This plan includes **adequate plant protein**, **unsaturated fats**, and **complex carbohydrates**, while keeping **animal products** and **added sugars** to a minimum. It also reflects the EAT-Lancet goal of feeding a growing population in a way that is both **nutritionally adequate** and **ecologically responsible**.

EAT-Lancet 2.0 — 2025 update

In 2025, the EAT Lancet Commission released a new, more comprehensive report — broadened from dietary guidance to a full evaluation of global food systems in light of human health, environmental limits, and social justice.

The 2025 report from the EAT-Lancet Commission offers the most comprehensive global scientific evaluation to date of how diets, food production, and food systems interact with human health, ecological stability, and social justice. It builds on the 2019 Planetary Health Diet framework — reaffirming the foundational dietary recommendations — but expands the scope dramatically.

Core dietary guidance (unchanged in principle)

- Emphasize **plant-based foods**: whole grains, legumes, nuts, seeds.
- Eat abundant **fruits and vegetables**.
- Use **unsaturated fats** (e.g., from nuts, seeds, vegetable oils), minimize saturated fats, processed foods, refined grains, and added sugars.
- Include **modest amounts** of animal-source foods (dairy, poultry, fish, eggs), adapted to cultural and regional contexts.
- Maintain **flexibility and diversity** — adapt the diet to local food availability, cultural practices, and economic realities.

A dietary pattern like the original PHD — e.g., oatmeal with nuts and fruit for breakfast; a whole-grain + legume + vegetable bowl for lunch; stir-fried tofu/tempeh (or occasional modest fish/poultry) with vegetables and whole grains for dinner; plant-based snacks — remains a valid, health-promoting, planet-friendly template.

Broadened scope: food systems, environmental boundaries, and justice

The 2025 Commission argues that healthy diets must be paired with **systemic transformation** of how we produce, distribute, and access food:

- Global food systems currently produce ~30% of human-caused greenhouse gases, and are a primary driver of breaches in five of nine critical Earth-system boundaries (climate, biodiversity, land use, freshwater, nutrient cycles, pollution from novel entities).
- With dietary shifts, reduced food loss/waste, and more sustainable agricultural practices, it is possible to more than **halve food-system emissions**, reduce land use, and keep food production within ecological "safe operating space."
- At the same time, the report highlights stark social inequities: fewer than 1% of people globally live in what it calls the "safe and just space," where access to healthy diets, decent wages for food workers, and ecological sustainability coincide.
- The wealthiest 30% of people account for more than 70% of food-related environmental impacts; nearly one-third of food-system workers earn below a living wage.
- Therefore, the transformation must also include **equity, fair labor, social justice, and governance reform** (e.g., support for sustainable agriculture, protection of traditional healthy diets, fair food environments, living wages, food accessibility).

Health and mortality gains

The Commission estimates that global adoption of a healthy diet under PHD-like principles could prevent **~11 million adult premature deaths per year** — roughly a 19–24% reduction in adult mortality. Depending on assumptions, some analyses estimate up to **15 million prevented deaths annually** if dietary shifts were widespread.

Why the 2025 update matters

The 2025 report demonstrates that the PHD remains scientifically robust — but also shows that the challenges of feeding a growing global population healthily and sustainably cannot be solved by dietary change alone. Achieving a healthy, equitable, and sustainable global food future requires structural transformation of food systems — including how we produce, distribute, regulate, and value food.

In other words: shifting the foods on our plates remains vital — but realizing the full potential of healthy, sustainable diets at scale depends equally on **societal action, food policy, social justice, and ecological stewardship**.

Animal Agriculture and Antibiotic Resistance

One of the biggest current threats to public health is ***antibiotic resistance***. Antibiotics are life-saving drugs, but over time, bacteria can develop resistance to them. This means that the antibiotics no longer work to kill the bacteria causing infections, leaving people with more severe illnesses and fewer treatment options, often needing to try different antibiotics that have more side effects. There are now some bacterial infections for which we have no working antibiotics to treat them. According to the CDC, at least 2.8 million people are infected with antibiotic-resistant bacteria each year in the U.S, and these infections are thought to kill at least 35,000 people annually.[5] Addressing this problem will require us to be more careful about how we use antibiotics, invest in research to develop new ones, and to develop other ways of preventing bacterial disease, such as new vaccines.

Antibiotics are important to both human and animal medicine. When we're sick with a bacterial illness, we may need antibiotics

to treat it, and the same is true of animals, whether they're raised for agriculture or part of our families as our pets. The problem is that the more we use antibiotics, the more chances bacteria have to evolve resistance to them, and the less effective those antibiotics become.

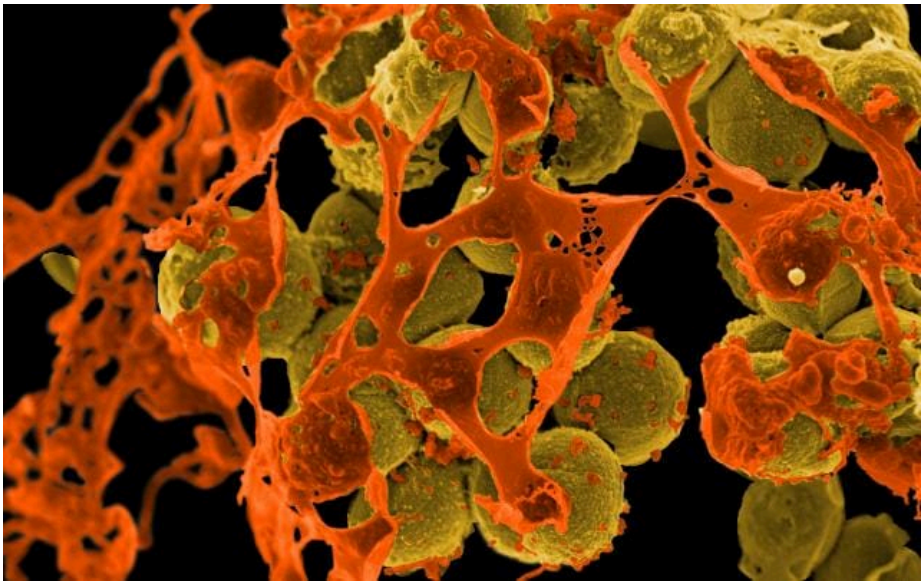


Fig. 6.27. Scanning electron micrograph of methicillin-resistant Staphylococcus aureus (MRSA, brown) surrounded by cellular debris. MRSA resists treatment with many antibiotics. Credit: NIAID

YouTube Video

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

The overuse of antibiotics in both human medicine and animal agriculture has contributed to the growth of antibiotic-resistant bacteria. For example, taking antibiotics for an illness caused by a virus, such as the common cold or the flu, won't make you better and just gives harmful bacteria chances to evolve resistance. Historically, antibiotics were also routinely given to food production animals to make them fatter, and that allowed for the growth of antibiotic resistance. As of 2017, the FDA ruled that antibiotics can no longer be used for growth promotion in animal agriculture, a significant step in reducing the overuse of these drugs that are important to both humans and animals. Data released by the FDA in December 2018 show that antibiotic sales for farm animals have dropped significantly after this rules change.[6]

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

When antibiotics are used in food animals, bacteria can evolve resistance to those antibiotics. Those antibiotics-resistant bacteria can then be present in your meat, and they can spread in the environment from animal feces, including into the water used to

irrigate fruits and vegetables. Humans exposed to these bacteria by handling or eating contaminated food can then become sick with infections that are resistant to antibiotic treatment, as shown in this infographic from the CDC:

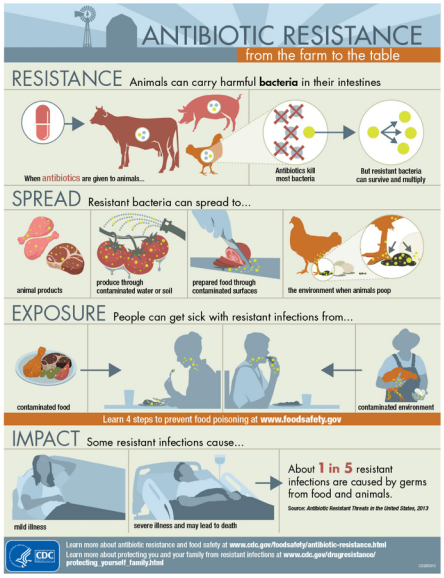


Fig. 6.28. Antibiotic Resistance from Farm to Table infographic from the CDC. Source: https://www.cdc.gov/foodsafety/challenges/from-farm-to-table.html

YouTube Video

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

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

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

When you shop for meat, milk, and eggs, you'll see lots of different types of labels making claims about how the animals

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

Choosing products that are certified organic ensures that antibiotics weren't used in their production, because organic farms are not allowed to use antibiotics even for sick animals.[7] (If an animal becomes sick and requires antibiotic treatment to get better, its milk, meat, or eggs can no longer be sold as organic, but it can be sold to a conventional farm.)

You'll also see labels stating "raised without antibiotics," and buying these products helps to support farmers and companies that have committed to reducing antibiotic use in their production systems, even if they aren't certified organic. However, ***antibiotic resistant bacteria*** (bacteria that have evolved resistance to antibiotics so could cause hard-to-treat infections) may still be present in products that are labeled certified organic or "raised without antibiotics" (the bacteria could have spread to these animals from somewhere else), so follow the food safety rules no matter where your meat comes from.[8]



Figure 6.29. These eggs are certified organic, so you can be confident that antibiotics weren't used in their production. The sausage is not organic, but it is made from chickens raised without antibiotics, so its production is unlikely to have contributed to the problem of antibiotic resistance.

More and more companies are also recognizing how the overuse of antibiotics can contribute to antibiotic resistance, and they're changing their practices. In December 2018, a large consortium of companies and industry groups, including Walmart, McDonald's, and Tyson Foods, committed to a framework for more responsible use of antibiotics.[9]

Additional reading:

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

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

Issues of Fish Sustainability

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

However, the oceans have been overfished, and global supplies of wild-caught fish are dwindling. Aquaculture, or fish farming, has also created new environmental challenges. Both of these issues are being solved with good management, like careful

limits on wild-caught fishing and new management practices for fish farming. You can encourage these practices by purchasing sustainably-sourced seafood.[10] The Monterey Bay Aquarium Seafood Watch program can help with this. You can download their app to help with buying decisions in the grocery store and find more information on their website: Monterey Bay Aquarium Seafood Watch.

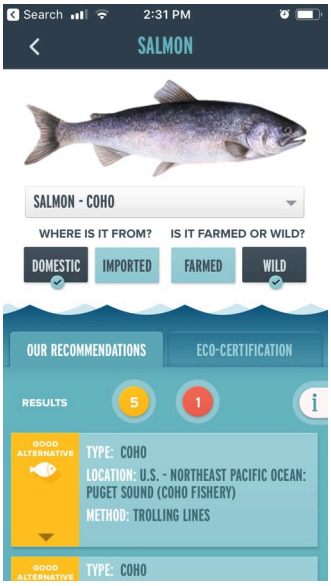


Fig. 6.30. A screenshot from the Seafood Watch app, showing how it can help you make sense of seafood buying options.

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

You may have also heard that fish can contain dangerous levels of mercury. This is true of some large species of fish that are higher up the food chain, because they accumulate mercury from their smaller prey and then we get a big dose when we eat them. **Fish that have dangerous levels of mercury include king mackerel, marlin, orange roughy, shark, swordfish, tilefish, and bigeye tuna**. Pregnant women and growing children in particular should take care to avoid these types of fish, because mercury can interfere with brain development. However, the same groups also stand to benefit from healthful omega-3 fatty acids, like DHA and EPA, which are *helpful* for brain development. Thus, it's good for pregnant women and children to eat fish, so long as they avoid the ones with high levels of mercury. Most common types of fish have lower levels of mercury and can be eaten at least once per week, if not two or three times per week[11]. Learn more at this FDA page: Eating Fish: What Pregnant Women and Parents Should Know.

Alternative Proteins

In recent years, the **Good Food Institute (GFI)** has emerged as a leading nonprofit and research-advocacy organization pushing innovation in **alternative proteins**, with the goal of reshaping how we produce dietary protein in ways that are better for human health, the climate, and global food security.

GFI defines alternative proteins broadly to include three main technological pathways: **plant-based formulations** (using protein isolates, concentrates, and texturization from soy, pea, wheat, mung bean, etc.), **precision fermentation** (where microorganisms are programmed to produce functional proteins, fats, or other ingredients), and **cultivated (cell-based) meat, seafood, and dairy** (where animal cells are grown in bioreactors). The appeal of these technologies is that they can replicate — or improve upon — the taste, texture, and nutritional profiles of conventional animal proteins while greatly reducing environmental burdens such as land use, greenhouse gas emissions, water use, and biodiversity loss. From a nutrition perspective, alternative proteins offer an opportunity to tweak macronutrient and micronutrient profiles (e.g. lower saturated fat, fortification with iron or B12) and to decouple protein supply from some of the health risks associated with industrial animal agriculture (e.g. antibiotic resistance, zoonotic disease). While the challenges are nontrivial — scale, cost, regulatory approval, consumer acceptance, and techno-functional performance — the rapid pace of investment and innovation suggests a growing diversity of alternative protein products will increasingly be available in coming decades.

Table: Categories of Alternative Proteins

Category	Description	Examples	Pros	Cons
Plant-Based	Proteins derived from legumes, grains, nuts, and seeds.	Beyond Meat, Impossible Burger, oat milk, almond yogurt	- Familiar to consumers - Scalable - Low in saturated fat, cholesterol-free	- May require additives for flavor/texture - Allergen concerns - Nutritional gaps
Fermentation-Derived	Microbes engineered or selected to produce proteins or fats via fermentation.	Perfect Day (dairy proteins), Quorn (mycoprotein), Motif FoodWorks	- Customizable ingredients - Animal-free dairy/egg - Lower environmental footprint	- New to market - Regulatory barriers - Less consumer awareness
Cultivated (Cell-Based)	Real animal cells grown in controlled environments (bioreactors).	GOOD Meat (chicken), UPSIDE Foods (beef/chicken)	- Real meat without slaughter - Reduces zoonotic risks - Potential for sustainability	- High cost - Limited availability - Requires regulatory approval

YouTube Video

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As an example of one of these alternative protein foods, Planting Change is a short film that explores plant-based nutrition as a potential strategy for supporting human health and environmental sustainability. Featuring perspectives from scientists, historians, and farmers, the video is produced by a company that develops plant-based foods. It is included here solely as an illustrative example of alternative protein development and industry perspectives, not as an endorsement of this company or its products.

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CHAPTER 8: ENERGY BALANCE, BODY WEIGHT AND HEALTH

Learning Objectives

After completing this unit, you will be able to:

1. Explain the concept of energy balance and how it relates to body weight, including the many factors that can influence both energy intake and expenditure.
2. Describe the characteristics of a healthy body composition, how it is estimated or measured, and limitations to these measures.
3. Describe the concerns with being underweight and overweight, appreciating that body weight may affect a person's health, at least in part due to the experience of living in a world with unrealistic expectations around body size and shape.
4. Explain how weight bias causes harm and can contribute to greater stress, increased body weight, and poorer health outcomes.
5. Describe the major types of eating disorders, including their risk factors, consequences, and treatment.
6. Identify the global trends in obesity worldwide, and identify possible causes and solutions.
7. Explain the challenge of and best practices for managing body weight and health, including non-diet and non-weight centric approaches.
8. Discuss the importance of a moderate approach when it comes to nutrition and weight management, recognizing that all foods can fit into a healthful diet.
9. Recognize that nutrition and its effect on our physical body is only one dimension of health, and others are equally important, including exercise, sleep, finding purpose, freedom from excessive stress, and community relationships.

8.1: Introduction to Body Weight and Health

8.2: Energy Balance- Energy In, Energy Out—Yet Not As Simple As It Seems

8.3: Measures of Body Size, Body Composition, and Metabolic Health

8.4: Risks of Too Little and Too Much Body Fat

8.5: Eating Disorders

8.6: Complex Causes of Excess Weight

8.7: Solutions for Improving Health

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8.1: Introduction to Body Weight and Health

On December 26, 2018, 33-year-old Colin O'Brady of Portland, Oregon, became the first person to cross the landmass of Antarctica solo, unassisted, and without any resupply shipments. Others had crossed the continent with the help of a wind sail to propel them over the ice or with resupply drops along the way—both ways of saving precious energy—but O'Brady completed the 926-mile trek only on skis, pulling a sled packed with food, fuel, and supplies the entire way. Speed was important, because he was racing another man, Louis Rudd, a 49-year-old British Army captain. And of course, he didn't want to run out of food hundreds of miles from the finish. Rudd finished the Antarctica crossing just two days after O'Brady.



Figure 9.1. Endurance athlete Colin O'Brady, photographed in March 2016

To prepare for the expedition, O'Brady and his team had to make careful calculations to estimate his nutrient and caloric needs. He'd be skiing all day, every day for about two months, in below zero temperatures and against constant wind. O'Brady estimated that he'd burn about 10,000 calories per day on his journey, and he knew that if he didn't pack enough food, he wouldn't have the strength to complete this epic test of endurance in extreme conditions. Previous explorers died in the Antarctic because they didn't pack enough food.



Figure 9.2. O'Brady and Rudd raced across a landscape similar to that shown in this photo from Antarctica—a polar desert and the coldest, windiest, driest continent on earth.

But O'Brady also knew that the more food he packed, the heavier his sled would be—ironically making him burn more calories, plus slowing him down and prolonging his trip. So he focused on making his food calorie- and nutrient-dense but lightweight: oatmeal with added oil and protein powder; freeze-dried dinners reconstituted with melted snow; and 4,500-calorie slabs of a custom-made "Colin bar" made from coconut oil, nuts, seeds, and dried fruit.

At the start of his journey, O'Brady's sled weighed 375 pounds and contained enough food to provide him with 8,000 calories per day. That was a bit short of the 10,000 calories he estimated he'd burn every day, so to build up some additional energy stores, he gained 15 pounds prior to his trip. In the end, after 54 days of skiing through ice and snow, he lost 25 pounds during his Antarctic crossing. He was successful, and while his fitness level and determination surely played a part, the trip would have been impossible without an adequate supply of calories.

In our daily lives, we need far fewer calories than an Antarctic explorer, and we don't need to schlep a two-month supply of food on our backs wherever we go. And thankfully, we get to enjoy fresher and more interesting food options, too. But each of us, every day, whether we're aware of it or not, is attempting to balance the calories we consume with the calories we burn, just like Colin O'Brady. This is the concept of **energy balance**—one we'll be exploring throughout this unit. If adults eat roughly the same number of calories as they burn each day, their body weight will generally stay very constant. If they burn more calories than they eat, like O'Brady was on his expedition, they'll lose weight. If they consume more calories than they burn, they'll gain weight.

Energy balance may seem like a simple concept, but in practice, how many calories a person eats and expends each day is influenced by so many different factors that it can be frustratingly difficult to apply. The human body has many sophisticated mechanisms that have evolved to help us protect and maintain our body weight, and in the history of our species, these mechanisms have been vital to our survival in times of food shortages. But today, we live in a world where highly palatable food is easily available and convenient, and we're constantly bombarded with marketing messages enticing us to eat more of it. At the same time, the diet industry and media send messages saying that being thin is the same as being healthy and that restrictive dieting is the virtuous path to wellness, which ironically may cause weight gain and worsen people's mental and physical health. Meanwhile, disparities in access to healthy food, safe places for physical activity, and healthcare have grown, all of which are associated with body weight and health. Many other factors, including the use of some medications, exposure to certain chemicals in the food supply and environment, inadequate sleep, excess stress, microbiome changes, and experiencing traumatic events, have been linked to body weight.

In this unit, we'll explore these complex concepts and concerns and seek some answers, but we acknowledge that we raise more questions than we resolve. The truth is that researchers don't fully understand why body weight has increased over the last several decades, much less how to change this trend. What is clear is that body weight is extraordinarily complex, and people have long been harmed by oversimplified messages to "eat less and move more" to reach a "normal" or "healthy" body weight. This approach implies that **obesity** is a failure of personal responsibility, but the last several decades have shown that blaming individuals for the size and shape of their bodies has not changed the trajectory of increasing body weight, and it has likely worsened people's health by harming their relationships with food and perpetuating weight stigma.

We have done our best to approach this topic with care, recognizing that it can be very personal. We know that the language used to describe people's bodies can be hurtful, and that encouraging people to engage in restrictive dieting practices for the purposes of making their bodies smaller can cause harm. Researchers' understanding of body weight regulation is incomplete and still evolving, and we have tried to include different perspectives in this unit. We hope you'll come away with an appreciation of the complexities, nuances, and uncertainties of this topic.

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8.2: Energy Balance- Energy In, Energy Out—Yet Not As Simple As It Seems

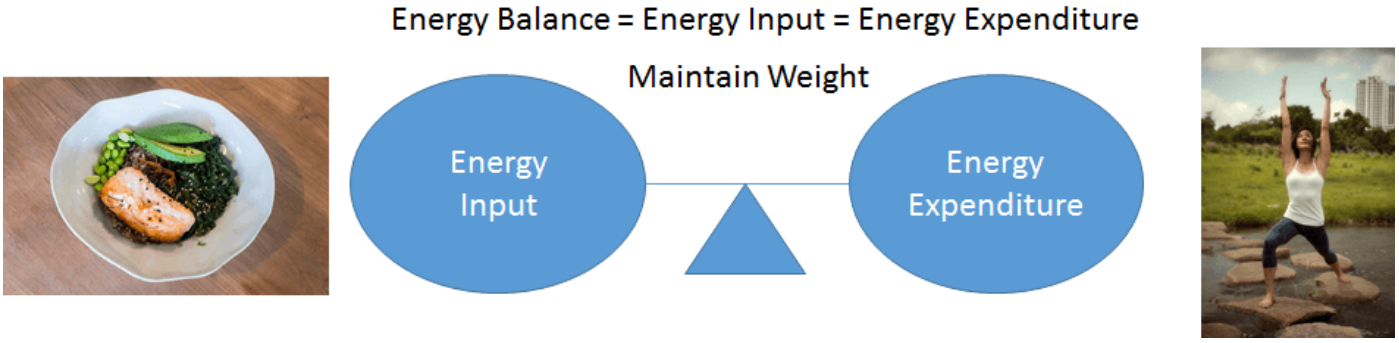
The concept of energy balance seems simple on paper. Balance the calories you consume with the calories you expend. But many factors play a role in energy intake and energy expenditure. Some of these factors are under our control and others are not. In this section, we will define energy balance, look at the different components of energy expenditure, and discuss the factors that influence energy expenditure. We'll also consider some of the factors that affect energy intake and consider why energy balance is more complex than it seems.

Energy Balance

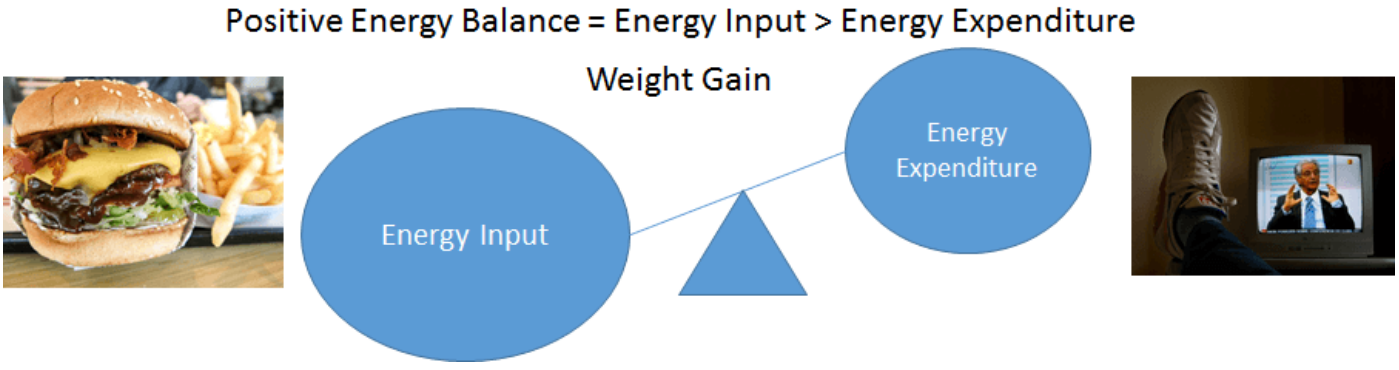
Our body weight is influenced by our energy intake (calories we consume) and our energy output (energy we expend during rest and physical activity). This relationship is defined by the ***energy balance equation***:

Energy Balance = energy intake – energy expenditure

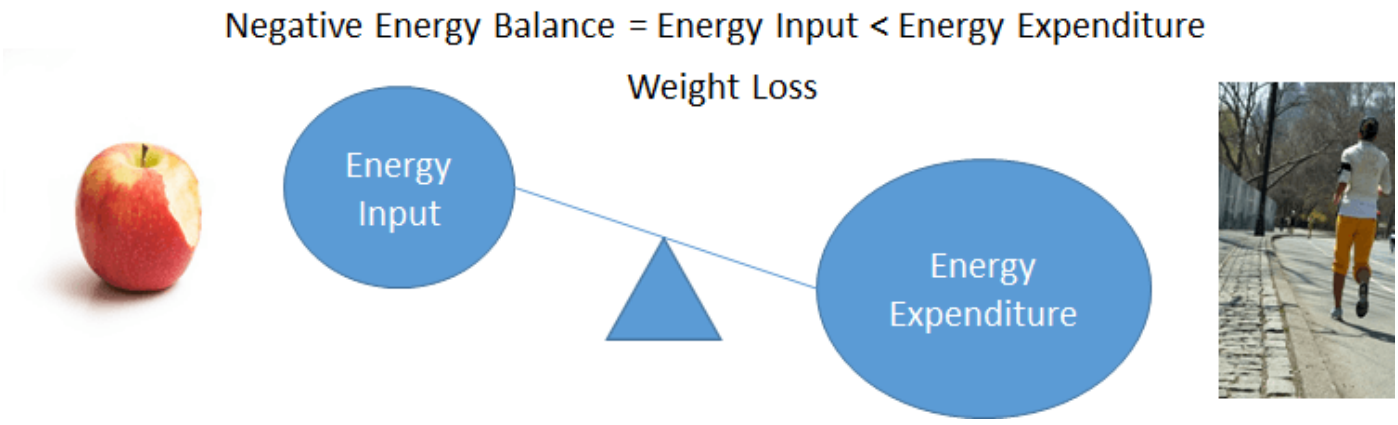
When an individual is in ***energy balance***, energy intake equals energy expenditure, and weight should remain stable.



Positive energy balance occurs when energy intake is greater than energy expenditure, usually resulting in weight gain.



Negative energy balance is when energy intake is less than energy expenditure, usually resulting in weight loss.



Energy intake is made up of the calories we consume from food and beverages. These calories come from the macronutrients (carbohydrates, proteins, and fats) and alcohol. Remember that when the body has a surplus of energy, this energy can be stored as fat. When the body has an inadequate supply of food calories to match energy expenditure, it will turn to stored energy (i.e., adipose tissue, glycogen, and some muscle protein) to meet energy demands, resulting in weight loss.

You may see simple rules about energy balance, such as the idea that a pound of fat contains 3,500 calories, so cutting 3,500 calories from your diet will result in a pound of weight loss. This is sometimes extrapolated to say that cutting your caloric intake by 500 calories per day will lead to one pound of weight loss per week, or 52 pounds of weight loss in one year. However, this is a myth, because the body responds to caloric restriction by making adjustments to energy expenditure and resisting changes in body weight, especially over long periods of time.[1]

Energy balance is complex, dynamic, and variable between individuals—something we'll explore a bit more later on this page—but it is still a vital concept in understanding body weight. Next, let's look at the energy expenditure side of the energy balance equation, to see the components that make up energy expenditure and the factors that influence them.

Components of Energy Expenditure

The sum of caloric expenditure is referred to as total energy expenditure (TEE).There are three main components of TEE:

1. Basal metabolic rate (BMR)
2. Thermic effect of food (TEF)
3. Physical activity

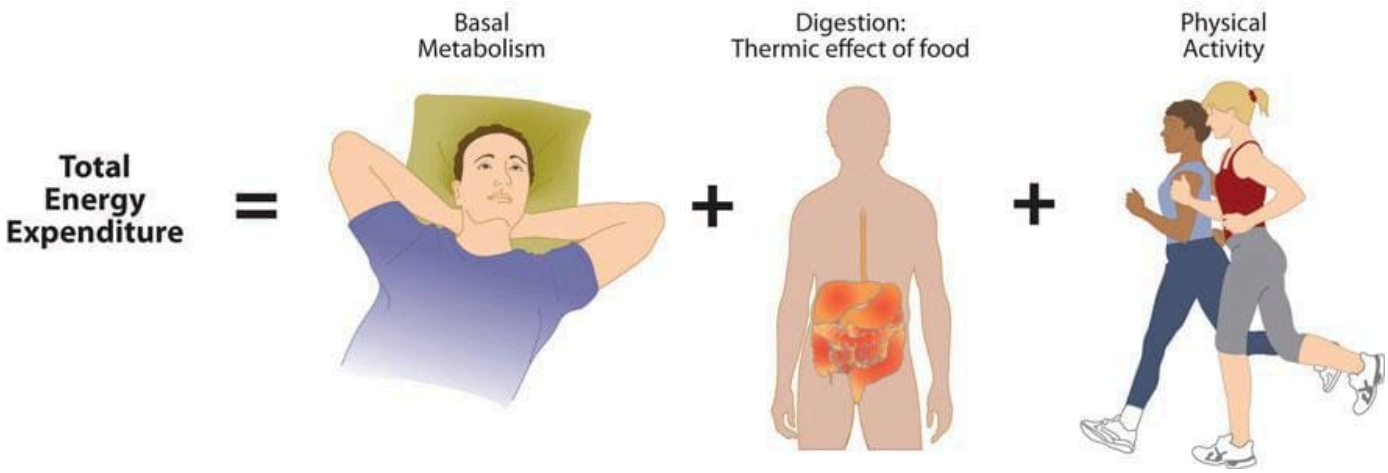


Figure 7.3. Components of total energy expenditure include basal metabolism, the thermic effect of food, and physical activity.

Basal Metabolic Rate (BMR)

BMR is the energy expended by the body when at rest. These are the behind-the-scenes activities that are required to sustain life. Examples include:

- respiration
- circulation
- nervous system activity
- protein synthesis
- temperature regulation

Basal metabolic rate does not include the energy required for digestion or physical activity.

If a person is sedentary or moderately active, BMR is the largest component of energy expenditure, making up about 60 to 75 percent of total energy output. For example, a sedentary person might need about 1800 calories in a day, with about 1200 of them being for BMR.

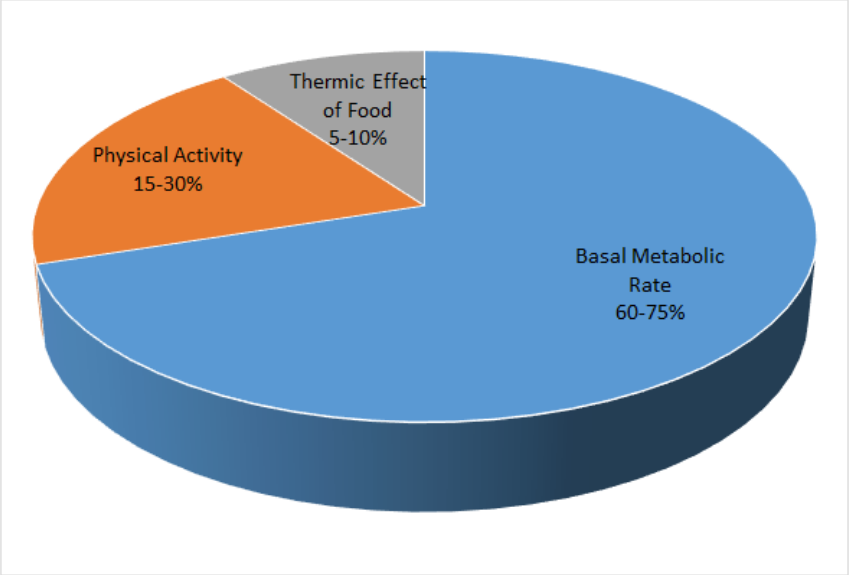


Figure 7.4. Components of energy expenditure and their percent contribution to the total in sedentary to moderately active people.

BMR can vary widely among individuals. An individual's lean body mass—made up of organs, bone, and muscle—is the biggest determinant of BMR, because lean body tissue is more metabolically active than fat tissue. This means that a muscular person expends more energy than a person of similar weight with more fat. Likewise, increasing your muscle mass can cause an increase in your BMR. However, skeletal muscle at rest only accounts for about 18 percent of the total energy expended by lean mass. Most is used to meet the energy needs of vital organs. The liver and brain, for example, together account for nearly half of the energy expenditure by lean mass.

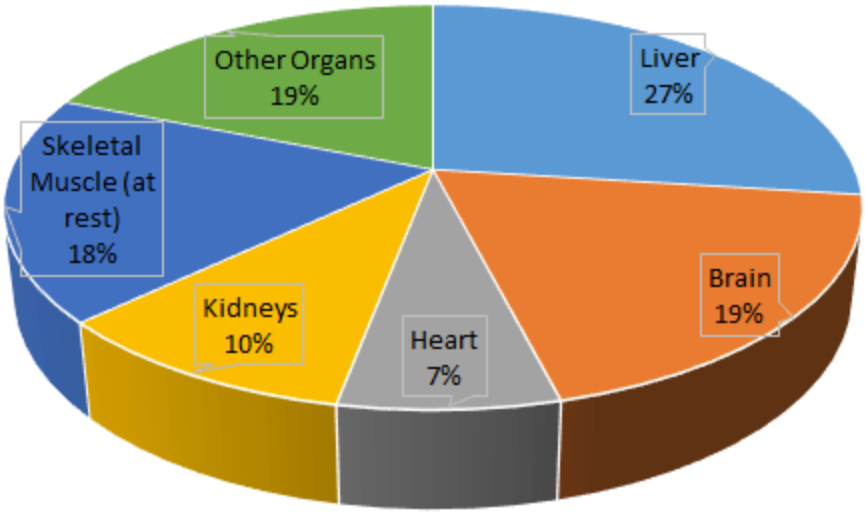


Figure 7.5. Energy expenditure of organs .

BMR depends not only on body composition but also on body size, sex, age, nutritional status, genetics, body temperature, and hormones (Table 7.1). People with a larger frame size have a higher BMR simply because they have more mass. On average, women have a lower BMR than men, because they typically have a smaller frame size and less muscle mass. As we get older, muscle mass declines, and therefore BMR declines as well.

Nutritional status also affects basal metabolism. If someone is fasting or starving, or even just cutting their caloric intake for a diet, their BMR will decrease. This is because the body attempts to maintain homeostasis and adapts by slowing down its basic functions (BMR) to help preserve energy and balance the decrease in energy intake. This is a protective mechanism during times of food shortages, but it also makes intentional weight loss more difficult.

Table 7.1. Factors that impact BMR.

Factors That Increase BMR	Factors That Decrease BMR
Higher lean body mass	Lower lean body mass
Larger frame size	Smaller frame size
Younger age	Older age
Male sex	Female sex
Stress, fever, illness	Starvation or fasting
Elevated levels of thyroid hormone	Lower levels of thyroid hormone

Factors That Increase BMR	Factors That Decrease BMR
Pregnancy or lactation	
Stimulants such as caffeine and tobacco	

Thermic Effect of Food (TEF)

This is the energy needed to digest, absorb, and store the nutrients in foods. It accounts for 5 to 10 percent of total energy expenditure and does not vary greatly amongst individuals.

Physical activity

Physical activity is another important way the body expends energy. Physical activity usually contributes anywhere from 15 to 30 percent of energy expenditure and can be further divided into two parts:

- exercise-related activity thermogenesis (EAT)
- non-exercise activity thermogenesis (NEAT)



EAT is planned, structured, and repetitive physical activity with the objective of improving health (participating in a sport like soccer or strength training at the gym, for example).

NEAT is the energy expenditure for unstructured and unplanned activities. This includes daily-living activities like cleaning the house, yard work, shopping, and occupational activities. NEAT also includes the energy required to maintain posture and spontaneous movements such as fidgeting and pacing.[2]

NEAT can vary by up to 2,000 calories a day for two people of similar size, according to Dr. James Levine, the Mayo Clinic researcher who first coined the term. NEAT may be an important component of obesity prevention and is currently an area of research.

Factors Affecting Energy Intake

Given the importance of energy's role in sustaining life, it's not surprising that energy balance is tightly regulated by complex

physiological processes. The brain (specifically the hypothalamus) is the main control center for hunger and satiety. There is a constant dialogue between our brains and gastrointestinal tracts through hormonal and neural signals, which determine if we feel hungry or full. Nutrients themselves also play a role in influencing food intake, because the hypothalamus senses nutrient levels in the blood. When nutrient levels are low, the hunger center is stimulated. Conversely, when nutrient levels are high, the satiety center is stimulated.

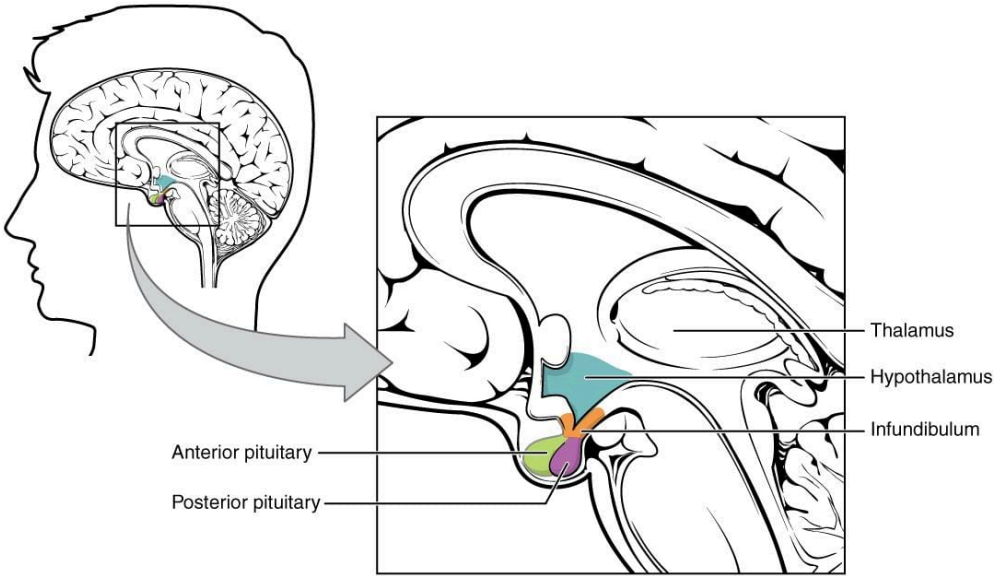


Figure 7.6. The hypothalamus, shown in blue, is about the size of an almond and serves as the hunger center of the brain, receiving signals from the gastrointestinal tract, adipose tissue, and blood and signaling hunger and satiety.

Hunger is the **physiological** need to eat. When the stomach is empty, it contracts and starts to grumble and growl. The stomach's mechanical movements relay neural signals to the hypothalamus. (Of course, the stomach also contracts when it's full and hard at work digesting food, but we can't hear these movements as well because the stomach's contents muffle the noise.) The stomach is also the main organ that produces and secretes the "hunger hormone," ***ghrelin***, the only gut hormone found to increase hunger. Ghrelin levels are high before a meal and fall quickly once nutrients are absorbed.[3]

Appetite is the **psychological** desire to eat. **Satiety** is the sensation of feeling full. After you eat a meal, the stomach stretches and sends a neural signal to the brain stimulating the sensation of satiety and relaying the message to stop eating. There are many hormones that are associated with satiety, and various organs secrete these hormones, including the gastrointestinal tract, pancreas, and adipose tissue. ***Cholecystokinin (CCK)*** is an example of one of these satiety hormones and is secreted in response to nutrients in the gut, especially fat and protein. In addition to inhibiting food intake, CCK stimulates pancreatic secretions, gall bladder contractions, and intestinal motility—all of which aide in the digestion of nutrients.[3]

Adipose tissue also plays a role in regulating food intake. Adipose is the primary organ that produces the hormone ***leptin***, and as fat stores increase, more leptin is produced. Higher levels of leptin communicate to the satiety center in the hypothalamus that the body is in positive energy balance. Leptin acts on the brain to suppress hunger and increase energy expenditure. The discovery of leptin's functions sparked excitement in the research world and the weight loss industry, as it was hypothesized that leptin might be used as a weight loss drug to decrease food intake. In several clinical trials, it was found that people who are overweight or obese are actually resistant to the hormone, meaning their brain does not respond as well to it. Therefore, when you administer leptin to an overweight or obese person, there is generally no sustained effect on food intake.[4]

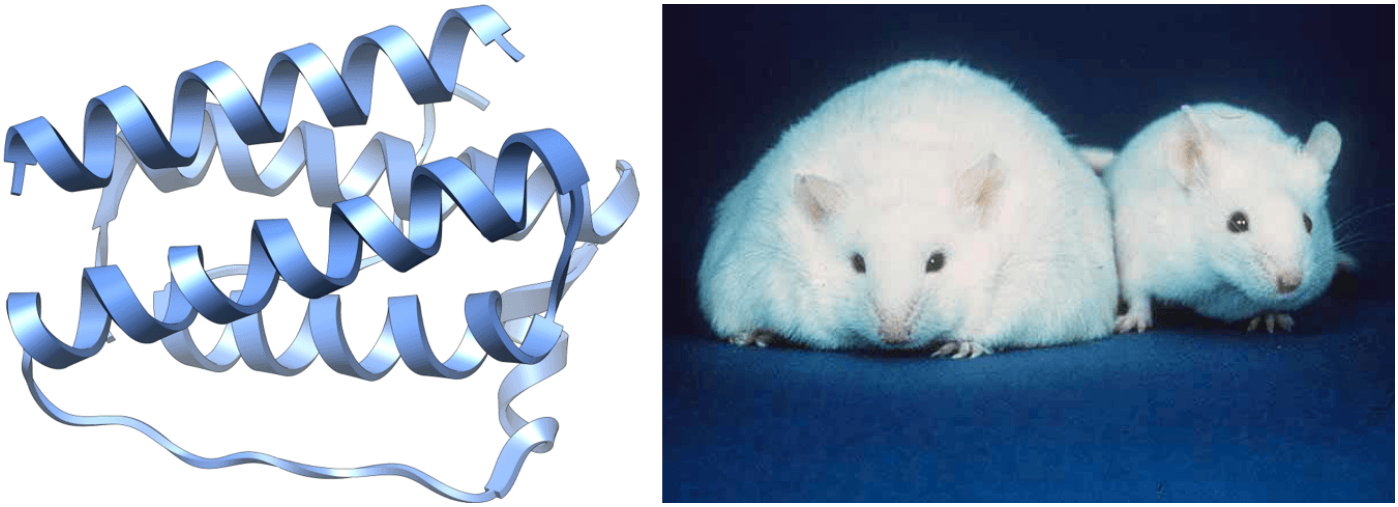


Figure 7.7. The structure of the hormone leptin (left), which is primarily produced by adipose tissue. The obese mouse in the photo has a gene mutation that makes it unable to produce leptin, resulting in constant hunger, lethargy, and severe obesity. For comparison, a mouse with normal leptin production is also shown. Such gene mutations are rare, but they serve as a dramatic illustration of the importance of the hormone in signaling energy balance.

The Complexity of Energy Balance

Energy balance seems like it should be a simple math problem, and in fact, it is based on a fundamental truth in physics—the first law of thermodynamics. This law states that energy can't be created or destroyed; it can only change form. That is, calories that are consumed must go somewhere, and if they aren't metabolized (which converts caloric energy to heat and work energy), they'll have to be stored, usually in the form of adipose tissue. What makes energy balance challenging is the reality that both energy intake and energy expenditure are dynamic variables that are constantly changing, in response to each other and overall energy balance.[5,6]

Let's first look at the energy intake side. As we've already discussed, **how much food we eat each day is not just a matter of willpower or self-control. It's the result of powerful physiological and psychological forces that tell us if we need to eat, or if we've had enough.** Our brains are hard-wired to seek food if we're in negative energy balance, an instinct required for survival. This means that if you start to exercise more—increasing your energy expenditure—you will also feel hungrier, because your body needs more fuel to support the increase in physical activity. If you eat fewer calories, perhaps in an effort to lose weight, your stomach will produce more ghrelin, and your adipose tissue will produce less leptin. These and other shifting hormone levels work together to increase hunger and make you focus on obtaining more calories. People who try to gain weight run into the opposite problem. Their leptin levels increase, suppressing hunger. It's also uncomfortable to eat beyond satiety, and food doesn't taste as good once you're full.

Even measuring how much energy is consumed is not as simple as you might think. We can measure the caloric content of food from a chemical standpoint, but we can only *estimate* how much energy a person will absorb from that food. This will depend on how well the food is digested and how well the macronutrients are absorbed—factors which vary depending on the food itself, the digestion efficiency of the person eating it, and even the microbes living in their gut. **Two people may eat the exact same meal, yet not absorb the same number of calories.**

Energy expenditure is also dynamic and changes under different conditions, including increased or decreased caloric intake. Decreased caloric intake and negative energy balance cause a drop in BMR to conserve energy. Muscles also become more efficient, requiring less energy to work, and without realizing it, people in negative energy balance often decrease their NEAT activity level. These adaptations help to conserve body weight and make it more difficult to stay in negative energy balance. People may still be able to lose weight despite their bodies working to prevent it, but maintaining a new, lower weight requires constant vigilance, and weight regain is common.

Research has also shown that people respond differently to positive energy balance. When a group of people are overfed, the amount of weight gained amongst study participants varies widely. In a study of identical twins who were given an extra 1,000 calories per day for 100 days, weight gain varied between 10 and 30 pounds among participants. Weight gain between twins was more similar (though not exactly the same), which may be attributed to genetic factors.[7] People gain and lose weight differently;

we don't necessarily follow formulas.

When people say that the answer to weight gain is to eat less and move more, they may be partially correct. But this is also an oversimplified answer, because of all the complexities underlying energy intake and energy expenditure.

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8.3: Measures of Body Size, Body Composition, and Metabolic Health

Healthy Body Size Is Personal

Ask a room full of people what the term "healthy body weight" means, and you'll probably get lots of different answers. This isn't surprising given that people naturally come in different shapes and sizes. In addition, body weight or fatness does not determine a person's health, and health encompasses not just physical health but also mental health and social well-being.

Here's how the authors of the text "Sport Nutrition for Health and Performance" describe a healthy body weight[1]:



- *A weight that is appropriate for your age and physical development*
- *A weight you can achieve and sustain without severely curtailing your food intake and constantly dieting*
- *A weight that is compatible with normal blood pressure, lipid levels, and glucose tolerance (in other words, you are metabolically fit)*
- *A weight that is based on your genetic background and family history of body shape and weight (after all the apple doesn't fall too far from the tree)*
- *A weight that promotes good eating habits and allows you to participate in regular physical activity*
- *A weight that is acceptable to you*

Another way of describing healthy body weight is "best weight," suggested in the 2020 Canadian Adult Obesity Clinical Practice Guidelines as a way for physicians working with patients who want to lose weight to help center their goals. **"Best weight" is described as "the weight that a person can achieve and maintain while living their healthiest and happiest life."**[2] It is thus not based on a number on the scale or a metric of body composition, but on individual bodies, lifestyle, and family history. It requires a truly individual assessment, and it isn't dictated by a formula, fad, or societal expectations.

Yet, the truth is that simple metrics are often used to assess body size and composition. We find them in online calculators, on scales at the gym, and in our doctors' offices. None of these metrics give anywhere near a complete picture of an individual's health or whether they are at their best weight. But it's worth understanding some of these measures so that you know what they mean when you encounter them, how they may be linked to health, and what their limitations are.

Body Mass Index

Body Mass Index (BMI) is a simple calculation used in clinical and research settings to assess body weight relative to height. BMI is easy and inexpensive to measure, and because it takes height into account, it is more predictive of how much body fat a person has than weight alone. However, BMI is not a direct measure of body fat, and it shouldn't be used on its own to make assumptions about the health of an individual.[3]

BMI is calculated using the following equations:

$$BMI = [weight\ (kg)/height\ (m^2)]$$

OR

$$BMI = [weight\ (lb)/height\ (in^2)] \times 703$$

The Centers for Disease Control and Prevention has a BMI calculator on its website.

For adults, BMI ranges are divided into four main categories:

- **Underweight –** BMI < 18.5
- **Normal weight –** BMI from 18.5-24.9
- **Overweight –** BMI from 25-29.9
- **Obesity –** BMI from 30 or higher

Obesity is frequently subdivided into categories:

- **Class 1 obesity:** BMI of 30 to < 35
- **Class 2 obesity:** BMI of 35 to < 40
- **Class 3 obesity**: BMI of 40 or higher

BMI values are interpreted differently for children, because body fatness changes so much during growth and varies with sex.[3]

BMI Interpretation in Populations

Because of its simplicity, BMI is a useful metric for researchers studying large groups of people. For example, BMI is used to track changes in body size within a population over time. It is also used in research studies looking at correlations between BMI and health conditions.

In general, studies have consistently shown that having a very low BMI or high BMI is associated with greater health risks, because there are health risks to carrying too little or too much body fat. When researchers have looked at BMI and health in large groups of people, they have often found that the lowest risk of dying younger is in the range of BMI of 20 to 25.[4-6] BMI values in the overweight and especially the obesity range have generally been found to be associated with higher rates of type 2 diabetes, cardiovascular disease, stroke, and some types of cancer, as well as other complications of obesity, such as osteoarthritis.[6-10]

However, which BMI range is associated with the best health outcomes is somewhat controversial, and different studies have come to different conclusions. For example, a meta-analysis published by CDC researchers in 2013 found that a BMI of 25 to 30 (classified as overweight) was associated with the lowest risk of mortality, and there was no difference between normal BMI or class 1 obesity in mortality risk.[11] We see a similar pattern in studies of specific health conditions. A 2022 study published in the Journal of the American Heart Association reported that among patients with coronary artery disease followed for 3 to 5 years, the risk of death was lowest in those with BMI of 25 to 35 (overweight to class 1 obesity).[12] In another recent study of people with type 2 diabetes, the risk of dying of cardiovascular disease or of having a heart attack or stroke was also lowest in people with BMI classified as overweight or class 1 obesity.[13]

The finding that overweight or mild obesity based on BMI can be associated with better health outcomes is often called the "**obesity paradox**," but some scholars argue that it is simply a reflection of our evolving understanding of the complex relationships between body size and health.[14] **Regardless, it is clear that health risks associated with different body sizes do not always align into neat BMI categories, and simple labels such as "normal" and "overweight" may not be very meaningful.**

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Video: What's in a Number? Some Research Shows That a Lower B.M.I. Isn't Always Better by Retro Report, YouTube (November 18, 2021), 10:41. This short documentary, produced in collaboration with Scientific American, covers how "biased ideas about a link between body size and health have led many people to dismiss unexpected findings."

Limitations of BMI for Individuals

We've discussed how BMI is an imperfect metric of health in population studies, but it has even more limitations when it comes to indicating an individual's body composition or health. For one thing, **since BMI is based only on weight and height, it doesn't distinguish between muscle mass and adipose tissue.** It's not unusual for muscular athletes to be classified as overweight based on BMI, yet have relatively little body fat. On the flip side, BMI can underestimate body fatness in someone with very low muscle mass, such as a person who is elderly and frail. In addition, **BMI can't tell us *where* body fat is located in the body, and as we'll learn, this is a major factor determining its impact on health.** BMI is also not useful for estimating body fatness in a pregnant person, because pregnancy weight gain includes placental and fetal tissues.[3]

BMI's accuracy in predicting body fatness is also affected by biological sex and race/ethnicity—not surprising given the natural diversity in human bodies. At the same BMI, women tend to carry more body fat than men. Also at the same BMI, a Black person tends to have less body fat, and a person of Asian descent tends to have more body fat, compared to a white person. This means that a high BMI may overestimate health risk in a Black person and underestimate health risk in a person of Asian descent.[3]

This natural variation means that using BMI as a universal metric to screen for body fatness and health risk can result in misleading conclusions. For example, Black Americans have, on average, higher BMI values and higher rates of obesity (defined by BMI) than white Americans, and this is especially true for women. However, the relationship between high BMI and mortality is weaker in Black Americans; in Black women, having a higher BMI has been found to be associated with a *lower* death rate.[16] Some scholars argue that using a crude metric like BMI in doctors' offices disproportionately harms Black women, who may be more likely to be told that weight is the cause of their health problems without acknowledging the gender- and race-related differences in BMI or the systemic issues — such as racism, poverty, pollution, and stress — that may be more important factors affecting their health.[17]

All of this means that BMI is not particularly useful for comparing one individual to another or even one population to another. **And for an individual, one BMI measurement at a single point in time is not all that meaningful; other measurements and clinical assessments are needed to evaluate disease risk, as we'll discuss in a moment.**

BMI is perhaps most useful for tracking *changes* in body composition over time, whether of a population or an individual. For example, the data on average BMI in the U.S. show a clear increase over the last several decades, and the most likely explanation for this trend is not that people in the U.S. are all gaining several pounds of muscle each year, but that we're carrying more fat. On the other hand, someone may have a BMI classified as overweight, but if they've been at that BMI their entire adult life and are active and metabolically healthy, they may be at their "best weight," and labeling them as "overweight" may be misleading and stigmatizing.

Measuring Body Composition

A person's body mass is made up of water, lean body mass (including organs, bone, and muscle), fat, and other components like minerals. The weight on the scale does not distinguish between these different components, but body composition measurements can.

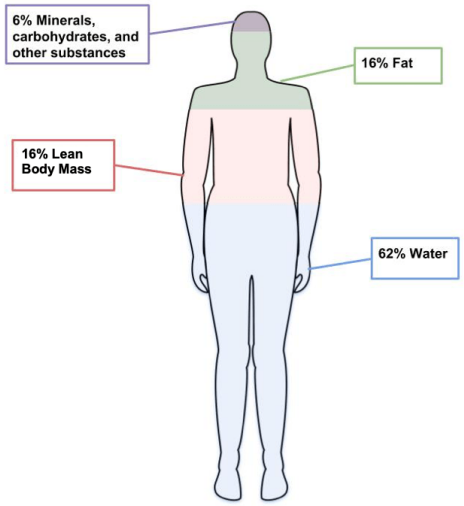


Figure 7.8. The four main components of body weight are water, fat, lean body mass, and other components like minerals.

Body composition measurements are sometimes used by individuals and researchers to determine how much of a person's weight is made up of body fat and lean body mass. For example, an individual might use body composition measurements to track their progress in building muscle with a new strength training program. Since increased body fat can be a risk factor for diseases like cardiovascular disease and diabetes, researchers are often interested in this type of data. There are several different methods used to measure body composition, each with advantages and limitations.[18]

- Skinfold Test. This is a simple, non-invasive, and low-cost way to assess fat mass. Calipers are used to measure the thickness of skin on three to seven different parts of the body, and these numbers are then entered into a conversion equation. The accuracy of the skinfold test depends on the skill of the person taking the measurements, the accuracy of the calipers, and the appropriateness of the conversion equations. Best practice is for the same person to take repeated measurements if using them to monitor changes over time. Repeated measurements by different technicians, using different calipers, and different conversion equations will yield very different results.

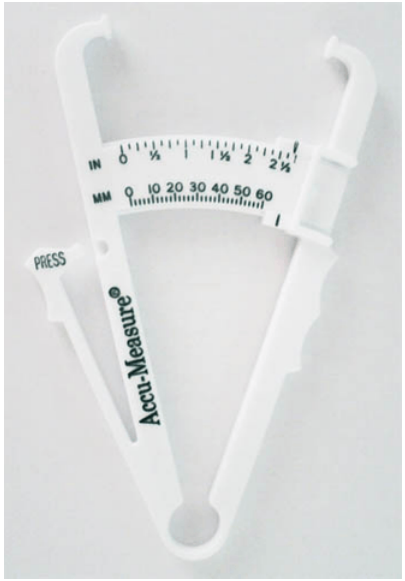


Figure 7.9. Calipers used to assess body fat during skinfold testing.

- **Bioelectric Impedance Analysis (BIA)**. This is a simple, non-invasive, quick tool that does not require extensive training.

BIA estimates body composition by sending a small amount of electricity through the body. Since water is a good conductor of electricity, and lean body mass contains more water than fat, the rate at which the current travels can be used to estimate percent body fat. Body fluid levels must be normal with BIA, which is a limitation, since hydration can be impacted by exercise, alcohol, and menstrual cycles.



Figure 7.10. BIA hand device.

- **Air Displacement Plethysmography (ADP).** This is a non-invasive, quick tool that does not take extensive training. It's more accurate but also more expensive than BIA. While a person sits inside an enclosed chamber (usually called a Bod Pod), changes in air pressure are used to determine the amount of air that is displaced in the test chamber, which can determine body volume. These measurements are then translated into percent body fat. Hydration status can affect the accuracy of this test. This test also needs to be conducted in a facility with a Bod Pod, so it is not as accessible as the skinfold test or the BIA.



Figure 7.11. Body composition measurement with whole-body air displacement plethysmography (ADP) technology or BodPod

- Dual-energy X-ray Absorptiometry (DXA). This method directs two low-dose X-ray beams through the body and determines the amount of energy absorbed from the beams. The amount of energy absorbed is dependent on the body's content of bone, lean tissue mass, and fat mass. Using standard mathematical formulas, fat content and bone density can be accurately

estimated. Although this is one of the most accurate methods of measuring fat mass, it is expensive and mostly used in research. It also requires low doses of radiation to the subject being tested, and is not appropriate for pregnant women.



Figure 7.12. Dual-Energy X-ray Absorptiometry (DXA)

Keep in mind that body composition can be hard to measure accurately when using inexpensive and accessible techniques like skinfold testing and BIA. Your best bet is to pick one method and use it over time to compare numbers and see how they change. Just don't get too hung up on the numbers, as their accuracy will be questionable depending on the method chosen. And just as there is no one body weight or BMI that is ideal for everybody, there is no one ideal body composition. Striving to hit a particular goal on the scale or on body composition measurements can lead to an unhealthy fixation on the numbers.

Measuring Fat Distribution

How fat is distributed in the body is important, **because people who store fat more centrally (apple-shaped) have a higher risk of chronic diseases like cardiovascular disease and type 2 diabetes compared to people who store fat in the hips, thighs, and buttocks (pear-shaped).** This is because visceral fat that surrounds vital organs (common in central obesity or apple-shaped fat patterning) is more metabolically active, releasing more hormones and inflammatory factors thought to contribute to disease risk compared to subcutaneous fat. Subcutaneous fat stored just below the skin (common in pear-shaped fat patterning) does not seem to significantly increase the risk for chronic disease. In fact, having more lower body subcutaneous fat such as in the hips and thighs may even protect against developing chronic diseases.[19]

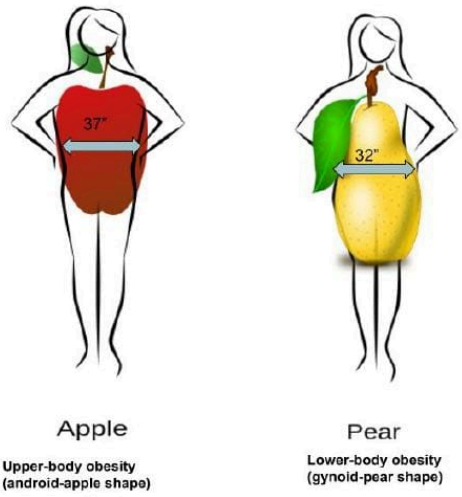


Figure 7.13. Fat can be located in the abdominal region (apple shape) or hips, thighs, and buttocks (pear shape).

Body fat distribution can be measured by waist circumference and waist-to-hip ratio, both of which only require a measuring tape.

- **Waist circumference** is measured just above the hip bone, level with your belly button. Men with a waist circumference greater than 40 inches and women with a waist circumference greater than 35 inches are predicted to face greater health risks.
- **Waist-to-hip ratio** is calculated by measuring waist circumference and hip circumference (at its widest part) and dividing the two values. Abdominal obesity is defined by the World Health Organization as a waist-to-hip ratio above 0.90 for men and above 0.85 for women.

Indicators of Metabolic Health

Metabolic health refers to the body's ability to maintain normal homeostasis and effectively regulate measures like blood pressure, blood lipids, and blood glucose. It is often assumed that when an individual is classified as overweight and obese based on measurements of BMI, body composition, and fat distribution, metabolic health is negatively impacted. However, some individuals who meet the criteria for obesity do not experience an increased risk of metabolic health.[20] These individuals are known as metabolically healthy obese (MHO). Metabolically healthy can be described as an absence of insulin resistance, type 2 diabetes, dyslipidemia, and hypertension.

Along the same lines, there are also individuals who are classified as normal weight (BMI < 25) but show an increased metabolic risk. These individuals are known as metabolically obese normal weight (MONW).



In a 2016 study, researchers analyzed BMI and measures of metabolic health (blood pressure, triglyceride and cholesterol levels, blood glucose, insulin resistance, and a marker of inflammation) for more than 40,000 Americans. Among the group classified as normal weight based on BMI, 69% were metabolically healthy based on measures of metabolic health, and 31% were metabolically unhealthy. In the higher BMI categories, the proportion of metabolically healthy people declined, but a significant number of individuals with larger body sizes had normal values for measures of metabolic health; 47% of people classified as overweight, 29% of those classified as having obesity, and 16% of those classified as having class 2 or 3 obesity were metabolically healthy.[21] In other words, **a person's body size is not an accurate indicator of their metabolic health, and it's important to measure and track more direct indicators of health and disease risk such as blood pressure, blood glucose, and blood lipid levels.**

These variations may challenge the assumptions we hold about body fatness. It can not be assumed that thinness equals health or that fatness indicates a lack of health.

Considerations for Transgender and Gender-diverse Individuals

In anthropometric and body composition assessment, standard metrics such as BMI, waist circumference, waist-to-hip ratio, and percent body fat must be interpreted cautiously. For example, hormone therapy (testosterone or estrogen) may shift fat distribution and alter lean mass, so normative cutoffs derived in cisgender populations may not fully apply. Clinicians should follow trends over time rather than rely solely on static thresholds, and where possible use body composition tools (e.g. DXA, bioimpedance) to track fat mass changes. Some clinicians may reference both male and female cutoff ranges or select whichever is most physiologically relevant given a person's hormonal milieu.

On the biochemical and clinical lab side, evaluators should include hemoglobin/hematocrit (for anemia or bleed risk), ferritin (iron stores), lipid profile including HDL-cholesterol (especially because hormone therapy may shift lipids), bone mineral density (BMD) via DXA (given risk of bone loss, particularly in gonad suppression phases), and markers of metabolic health (glucose, insulin, liver enzymes, etc.). Over time, clinicians should anticipate possible reductions in HDL-cholesterol in some hormone regimens and monitor bone density especially in those receiving gonadal suppression or inconsistent hormone dosing.

In sum, nutrition guidance for transgender individuals should be gender-affirming, individualized, and dynamic, with careful use of multiple assessment domains rather than overreliance on any single "reference" value.

YouTube Video

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Video: Nutrition Assessment for Transgender and Gender-Diverse Patients hat's in a Number? by **Dietitians in Nutrition Support** YouTube (May 27, 2025), 20:21. Join Dr. Jennifer Waters and Dr. Whitney Linsenmeyer as they share about best practices for conducting a nutrition assessment with patients or clients who identify as transgender or gender-diverse. They will share about gender-affirming communication as well as gender-affirming treatments, including hormone regimens and their impact on biochemical markers.

Self-Check:

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8.4: Risks of Too Little and Too Much Body Fat

As the previous section illustrated, most measures of body composition are imperfect estimates, and they are often not accurate indicators of health. However, in general, carrying too little and too much body fat are both correlated with greater health issues.

We see this pattern in studies of mortality risk and BMI, which usually report a J-shaped curve indicating a greater risk of dying sooner at low and high BMI. **The lowest average mortality risk is usually found somewhere between BMI values of about 20 and 30, corresponding to normal and overweight BMI categories. Which BMI category is correlated to the lowest mortality risk is controversial, and different studies have reached different conclusions depending on the population studied and the statistical methods used.** Most studies find the lowest mortality rate in the normal range with little to no increase in mortality in the overweight range for BMI,[1-3] and some find that the overweight group has the lowest mortality rate.[4-6]

As an example, the results of a 2018 study of 3.6 million adults in the UK are shown below.[1] You can see that the relationship between BMI and mortality rate varies by biological sex and age group, but the general pattern holds.

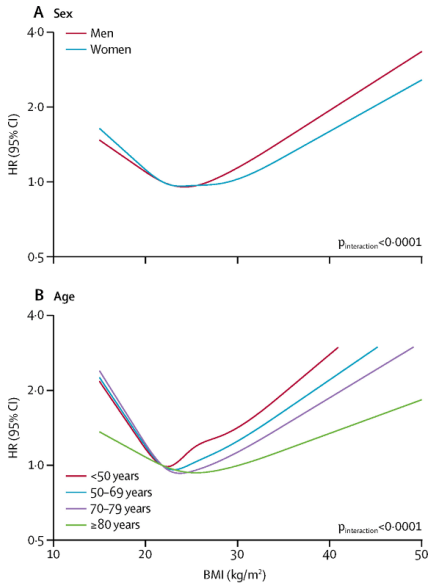


Figure 7.14. The relationship between BMI and mortality risk (higher HR on the y-axis indicates higher risk of dying during the study) forms a J-shaped curve, which can vary depending on factors like sex and age. This example is from Bhaskaran et al. (2018) and illustrates the typical pattern seen in similar studies, although the exact placement of the curve along the BMI scale varies between studies.

What are the specific risks associated with carrying too little or too much body fat? Let's take a closer look at each of these situations.

Health Risks of Being Underweight

The 2017–2018 National Health and Nutrition Examination Survey (NHANES) estimated that 1.6 percent of adults and 4.1 percent of children and adolescents in the United States are underweight.[7,8] Underweight individuals represent a small portion of Americans, yet the health risks associated with being underweight are an important part of the discussion on nutrition and health. Globally, the World Health Organization estimated that in 2014, approximately 462 million adults were underweight.[9]

Keep in mind that BMI is used to classify underweight, and just as it's a crude measure for estimating health risks associated with higher body fat, the same can be true for underweight. Some people are genetically predisposed to be lean, and they may be at their "best weight" even if their BMI classifies them as underweight.

Adipose tissue plays important roles in the body. It is our largest form of energy storage, helping us to survive during periods of low food supply and storing extra energy during periods of abundance. Adipose also provides insulation and padding, and it produces hormones and other signals that regulate metabolism and support immune function. It is critical for reproductive function, including normal secretion of sex and reproductive hormones, pubertal development, pregnancy, and lactation.[10]

Being underweight has been shown to be associated with an increased risk of several health conditions:[11-16]

- Osteoporosis and low bone mineral density
- Increased risk of infection, delayed wound healing, and greater post-surgical complications
- Cardiovascular disease, including stroke, heart attack, and coronary heart disease
- Some cancers, plus poorer response to treatment and survival rates after diagnosis
- Irregular menstrual cycles, decreased fertility, and poorer pregnancy outcomes
- Depression in women
- Decreased semen quality in men
- Stunted growth in children

The most common underlying cause of underweight in the U.S. is inadequate nutrition, which may occur because of lack of access to enough food; difficulty eating or digesting food, which is common in older adults; or disordered eating. Note that eating disorders do not always cause underweight and can be present in people of all body sizes. Eating disorders are covered in greater depth on the next page.

Other causes of underweight include wasting diseases like cancer, multiple sclerosis, and tuberculosis. People with wasting diseases are encouraged to seek nutritional counseling, as a healthy diet greatly affects survival and improves responses to disease treatments.

Health Risks of Excess Body Weight

In 2017-2018, it was estimated that 42 percent of adults and 19 percent of children in the United States had obesity.[17-18] Globally, the prevalence of obesity was estimated to be 13 percent of adults and 7 percent of children and adolescents in 2016. According to the World Health Organization (WHO), overweight and obesity are linked to more deaths worldwide than underweight.[19]

Carrying too much body fat can affect health through several mechanisms. Fat cells are not lifeless storage tanks—they're dynamic, metabolically-active tissue that secrete a number of different hormones and hormone-like messengers, causing low-grade inflammation that's believed to contribute to chronic disease development such as type 2 diabetes, cardiovascular disease, and some types of cancer.[20] Carrying more body weight can also contribute to joint problems and difficulty with mobility.

According to the Centers for Disease Control and Prevention, obesity is associated with an increased risk of the following health conditions[21]:

- High blood pressure and high cholesterol, which are risk factors for heart disease
- Type 2 diabetes
- Breathing problems such as asthma and sleep apnea
- Joint problems such as osteoarthritis and musculoskeletal discomfort
- Gallstones and gallbladder disease
- Stroke
- Many types of cancer
- Depression and anxiety

Children with obesity face many of these same health risks, and they are more likely to have obesity as adults. Obesity in children is also associated with lower self-esteem and facing greater social challenges such as bullying and stigma.[21]

As we discussed on the previous page, a significant number of people living in larger bodies—who might be classified as overweight or obese based on BMI—are metabolically healthy.[22] **Health issues may be more common in people carrying more fat, but many other factors are at play, including genetics, the location of body fat (subcutaneous or visceral), diet quality, physical activity, socioeconomic factors, and environmental factors.** Most of the studies on obesity and health conditions are observational, and as we covered in Unit 2, observational research can only show correlations, not causation. And

with so many overlapping factors involved, it can be difficult to tease apart correlation and causation. For example, a person with a family history and genetic predisposition for diabetes or heart disease might also have a genetic predisposition for higher body weight, so it is difficult to say whether or how much higher body weight contributed to the development of disease.

Likewise, as we'll discuss later in the unit, factors such as access to healthcare and education, food security, poverty, neighborhood safety, housing stability, stress, and racism can affect both body weight and health. These factors are called **social determinants of health** and are defined by the CDC as "conditions in the places where people live, learn, work, and play that affect a wide range of health risks and outcomes." If a person living in a larger body has health problems, we shouldn't assume that those problems are caused by their weight, as there could be numerous contributing factors.[23] In addition, many of the health problems associated with obesity can be mitigated by lifestyle changes such as increased physical activity or improved diet quality, so just as excess weight may not be the sole cause of associated health issues, weight loss is also not the only answer.[24]

To further add to the complexity of this discussion, studies of the relationship between weight and health rarely account for the effects of weight stigma. As we'll discuss in more detail below, research has shown that experiencing **weight stigma may contribute to both weight gain and poorer health outcomes**. In this sense, some of the health problems associated with higher body weight may not be because of the weight itself but because of how others treat people with larger bodies.[25,26]

All of that said, recent studies have used innovative study designs that incorporate genetic data to better understand the complex relationship between body weight and health conditions. These studies generally find that, although the relationship is neither simple nor the effects universal, excess weight does contribute to increased risk of many health conditions.[27-29]

Effects of Weight Bias and Stigma

According to the 2020 Joint International Consensus Statement for Ending Stigma of Obesity, "***weight stigma*** refers to social devaluation and denigration of individuals because of their excess body weight, and can lead to negative attitudes, stereotypes, prejudice, and discrimination." The statement, which was authored by 36 experts from around the world, is a call to action for healthcare professionals, policymakers, and the public to end weight stigma.[30] It begins:

"Individuals with obesity face not only increased risk of serious medical complications but also a pervasive, resilient form of social stigma. Often perceived (without evidence) as lazy, gluttonous, lacking will power and self-discipline, individuals with overweight or obesity are vulnerable to stigma and discrimination in the workplace, education, healthcare settings, and society in general. Weight stigma can cause considerable harm to affected individuals, including physical and psychological consequences. The damaging impact of weight stigma, however, extends beyond harm to individuals. The prevailing view that obesity is a choice and that it can be entirely reversed by voluntary decisions to eat less and exercise more can exert negative influences on public health policies, access to treatments, and research."

"About 40% of the general population reports that it has experienced some type of weight stigma—whether it be weight-based teasing, unfair treatment, or discrimination," said Rebecca Puhl, PhD, deputy director of the Rudd Center for Food Policy & Obesity at the University of Connecticut, in Today's Dietitian.[31] Weight stigma can be experienced in nearly every aspect of life, including the workplace, healthcare, social settings, and even within a person's own family.

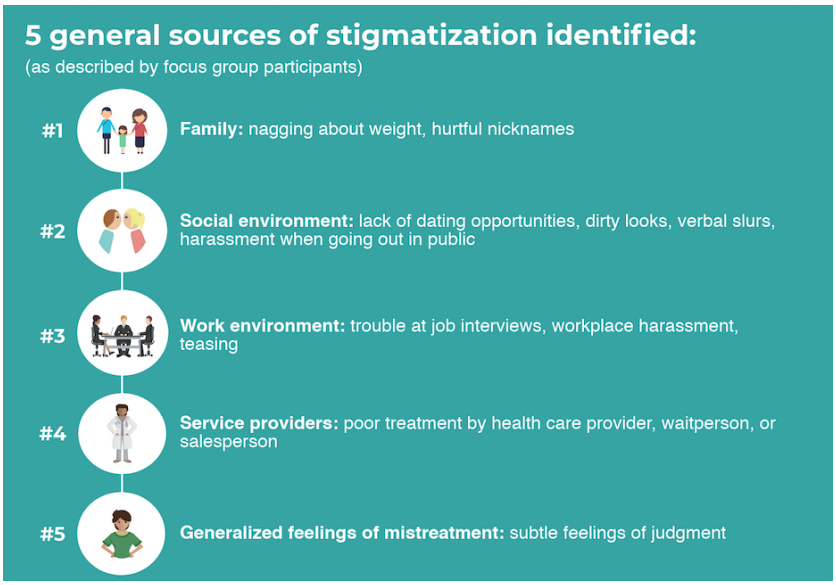


Figure 7.15. Common sources of weight stigmatization identified by individuals who are overweight or obese include families, social environments, work environments, and service providers, as well as generalized feelings of judgment from others. Source: Cossrow, N. H., Jeffery, R. W., & McGuire, M. T. (2001). Understanding weight stigmatization: A focus group study. Journal of nutrition education, 33(4), 208-214.

Experiencing weight stigma has been associated with many negative physical and mental health outcomes[30]:

- Lower self-esteem and greater levels of depression, anxiety, social isolation, stress, and substance use
- Unhealthy eating and weight control behaviors, such as binge eating
- Exercise avoidance and lower levels of physical activity
- Greater weight gain over time
- Higher levels of inflammatory markers and stress hormones
- Greater long-term cardiometabolic risk and increased mortality
- Lower quality medical care, poorer treatment outcomes, and avoidance of medical care

It is important to note that these effects have been shown to be associated with experiencing weight stigma, above and beyond the consequences of excess body weight. And as noted above, this research points to weight stigma as one of the factors that contributes to poorer health among people with larger bodies.



Combatting weight stigma and discrimination will require change on many levels. Governments can include weight as a category covered in anti-discrimination laws. Anti-bullying efforts at the school level should include policies on harassment and bullying related to weight. Healthcare should include reimbursement for obesity treatment, and weight bias training should be required for healthcare providers. Providers should ensure that their facilities are comfortable and welcoming to people of all sizes, and that they offer evidence-based care and treatment options to all patients, regardless of their size. And education and awareness about weight bias on an individual level will help change negative attitudes toward overweight and obesity.[30,32]

YouTube Video

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VIDEO: "Weight of the Nation: Stigma—The Human Cost of Obesity" by HBO Docs, YouTube (May 14, 2012), 18:54. This is video helps increase awareness of weight stigma, humanizing the pain and damage caused by weight bias and discrimination.

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Query 8.4.1

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8.5: Eating Disorders

In any conversation about weight and health, it is important to understand the risk and prevalence of eating disorders. The National Institute of Mental Health (NIMH) defines eating disorders as “serious and sometimes fatal illnesses that cause severe disturbances to a person’s eating behaviors.”[1] People with eating disorders often experience a preoccupation with food choices and body weight, and they frequently have a distorted body image, believing that self-worth is tied to body size and shape.[2] Eating disorders are serious and complex health conditions, and their prevention, proper diagnosis, and treatment must involve a multi-faceted approach, including physical, emotional, and social issues related to each individual’s needs.[3]

The short video below summarizes the main types of eating disorders, and you’ll find sections with more details on each type further down this page.

YouTube Video

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VIDEO: “Eating Disorders: What Are They?” by the National Eating Disorders Association, YouTube (August 3, 2018), 3:28. This short video offers a summary of the characteristics of the main types of eating disorders.

Researchers have estimated that about 9 percent of people living in the United States, or 28.8 million Americans, will have an eating disorder in their lifetime.[4] The prevalence of eating disorders also seems to be increasing.[5] Eating disorders can be accompanied by many health complications, and **among all mental illnesses, eating disorders have one of the highest fatality rates.** Anorexia nervosa in particular can be deadly; it has the second highest mortality rate of mental illnesses, outranked only by substance use disorder.[6] Eating disorders cause approximately 10,200 deaths each year, or one death every 52 minutes in the United States.[4] In a large study of U.S. college students published in 2020, those with the greatest level of eating disorder symptoms were 11 times more likely to have attempted suicide compared with those who did not have an eating disorder.[7]

If you or someone you know is in crisis and needs immediate help, call the toll-free National Suicide Prevention Lifeline (NSPL) at 1-800-273-TALK (8255), 24 hours a day, 7 days a week.

Historically, there has been a stereotype of eating disorders typically affecting young, white, straight women and resulting in a visibly underweight body. But this is a false stereotype. **Eating disorders can affect anyone, regardless of their background, body size, gender, sexuality, race, ethnicity, or age.** This is an important point because misconceptions about who is affected by eating disorders have resulted in these illnesses being underrecognized, undiagnosed, and untreated in people who don’t fit the stereotype.[8]

YouTube Video

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

View this YouTube Video online

VIDEO: "People of color with eating disorders face cultural, medical stigmas" by PBS Frontline, YouTube (March 28, 2022), 9:19. This video is a report on how and why eating disorders are often overlooked in people of color.

Risk factors for eating disorders are multifactorial. The National Eating Disorders Foundation lists the following risk factors for eating disorders[9]:

- **Biological Factors**
  - Having a close relative with an eating disorder or other mental health condition
  - History of dieting or negative energy balance
  - Having type 1 diabetes
- **Psychological Factors**
  - Perfectionism
  - Body image dissatisfaction
  - Personal history of an anxiety disorder
  - Behavioral inflexibility (always following the rules or feeling there is one "right way" to do things)
- **Social Factors**
  - Experiencing weight stigma
  - Experiencing teasing or bullying
  - Believing there is an "ideal body"
  - Having a limited social network
  - Acculturation, such as when people of different ethnicities are introduced to Western media that emphasizes diet culture and an ideal body shape
  - Having experienced historical or intergenerational trauma, such as Holocaust survivors and Indigenous groups that experienced colonization

It is especially important to note how dieting and weight stigma are associated with the risk of developing an eating disorder. For example, in one U.S. survey, adults who reported experiencing weight stigma were more likely to have disordered eating, regardless of BMI.[10] In another study, 14-year-old girls who were told by a family member or another person in their life that they were "too fat" were, at age 19, more likely to be dissatisfied with their body and to be using unhealthy weight control behaviors, such as vomiting, taking diet pills, and using laxatives. These effects were seen regardless of BMI, meaning that these unhealthy outcomes also occurred in girls with a normal weight BMI who were labeled by others as "too fat."[11] In one cohort of teens followed for three years, those who dieted were five times more likely to develop eating disorders, and those who were on severely restrictive diets were 18 times more likely to develop eating disorders.[12]

Note

Eating Disorder Risk and Protective Factors Among Transgender and Gender-Diverse Individuals

Transgender and gender-diverse individuals are 4.6 times more likely to be diagnosed with an eating disorder and 2 to 2.5 times more likely to engage in behaviors such as vomiting, laxative use, or diet pill consumption (Gold et al., 2024). Among youth, these behaviors often begin between ages 12 and 14 and are significantly more prevalent among transgender students in grades 9–12 compared to their cisgender peers (Ferrero et al., 2023). Non-binary individuals are also more likely than binary transgender people to receive an eating disorder diagnosis (Gomes et al., 2021). These disparities are driven by intersecting factors such as stigma, discrimination, and gender dysphoria—where food restriction or weight manipulation may be used to align one's body with gender identity. Encouragingly, access to gender-affirming care has been linked to lower rates of eating disorder symptoms and healthier eating behaviors, underscoring its role as a critical protective factor (Gomes et al., 2021). Source: Johnson, N. E. (2025). *Moving beyond binary: Nutrition and health considerations for transgender and gender-diverse populations* [Unpublished Fact Sheet]. University of California, Berkeley.

It's also worth noting that **dieting in young people is actually linked to greater weight gain over time, not less. For these reasons, the American Academy of Pediatrics discourages dieting in young people and recommends that families concerned about a child's body weight focus on adopting healthy and sustainable eating and physical activity patterns rather than trying to change weight.**[13] When we talk about weight management interventions or public health policies, it's important to be mindful of the risks of overly restrictive diets or practices that stigmatize people based on weight.

With proper diagnosis and treatment, people can recover completely from eating disorders. Treatment can involve individual, group, and/or family psychotherapy; medical care and monitoring; nutrition counseling; and medications such as antidepressants and mood stabilizers. A registered dietitian is often a vital part of the treatment team.[1]

Anorexia Nervosa

Anorexia nervosa, often referred to as simply "anorexia," is an eating disorder characterized by severe restriction of the amount and often types of foods eaten due to an obsession about body weight, fear of gaining weight, and/or a distorted body image. Anorexia results in extreme nutrient inadequacy, weight loss and/or failure to grow normally, and eventually organ malfunction. A 2019 review of studies estimated that 1.4 percent of women and 0.2 percent of men will have anorexia at some point in their lifetime.[14] Anorexia often begins during adolescence, but it can emerge much later in adulthood. In addition to severe food restriction, some people with anorexia also may exercise compulsively and have binge-eating and purging episodes, during which they eat large amounts of food and then purge it by vomiting or using laxatives or diuretics.[1] Though some people with anorexia are noticeably underweight, the disorder can also affect people in larger bodies, who may be less likely to be diagnosed because of their size.[15]

Anorexia can affect mental and physical health in many ways. It can cause excessive weight loss, osteoporosis, anemia, muscle wasting and weakness, brittle hair and nails, skin abnormalities, growth of fine hair all over the body, severe constipation, low blood pressure, slowed pulse and breathing rate, low body temperature, fatigue, infertility, menstrual irregularities or loss of periods, heart and brain damage, and organ failure.[1] The goals of treatment for anorexia are to restore a healthy body weight and significantly reduce the weight obsession and behaviors associated with the eating disorder.



Bulimia Nervosa

Bulimia nervosa is characterized by episodes of eating large amounts of food followed by purging, which is accomplished by vomiting or the use of laxatives and diuretics. People with bulimia often feel a lack of control over these episodes. The prevalence of bulimia is estimated to be 1.9 percent in women and 0.6 percent in men.[14] People with bulimia typically have a BMI in the normal weight or overweight range; underweight is less common.[16]

Signs and symptoms of bulimia include a chronically inflamed and sore throat, swollen salivary glands, gastric reflux, severe erosion of tooth enamel due to exposure to stomach acid, intestinal distress, dehydration, and electrolyte imbalances, which can lead to stroke or heart attack.[1]



Figure 7.16. This photo shows the erosion on the lower teeth caused by bulimia. For comparison, the upper teeth were restored with porcelain veneers.

Binge-Eating Disorder (BED)

Like those with anorexia or bulimia, people with binge-eating disorder (BED) have lost control over their eating. They will periodically overeat to the extreme, often quickly and to the point of discomfort, but their loss of control over eating is not followed by fasting, purging, or compulsive exercise. BED may be diagnosed at any weight, but compared with other eating disorders, is more often seen in people living in larger bodies.[1] BED is the most common eating disorder in the U.S.; it has been estimated to affect 2.6 percent of people in their lifetime. Unlike bulimia and anorexia, which often begin in adolescence, the average age of onset of BED is 23 years of age.[17] There may be a link between dieting and BED, as many people with BED also have a history of dieting, and restricting food intake may increase the urge to binge.[18]

The health consequences of BED are those linked to weight stigma and having a higher body weight, such as hypertension, cardiovascular disease, type 2 diabetes, and chronic pain. Additionally, people with BED often experience guilt, shame, and depression, and BED is also associated with phobias, social anxiety, posttraumatic stress disorder, and alcohol use disorder.[18] Treatment often involves psychiatric and nutritional counseling as well as medications to treat depression or other mental health conditions.[1]

Orthorexia Nervosa

Orthorexia nervosa is a newer disordered eating behavior defined as an obsession with healthy eating. The term “orthorexia” was first defined in 1998, but it has yet to be formally classified as an eating disorder, making it difficult to determine how prevalent it is. Research suggests it may be identified as a form of obsessive-compulsive disorder. While focusing on a healthy diet isn’t inherently a bad thing, a person with orthorexia takes the emphasis on healthy or “clean” eating to the extreme, so much so that it becomes a fixation, putting their health at risk. Signs of orthorexia include compulsively reading food labels, cutting several food groups out of the diet, spending an unusual amount of time focusing on what foods may be available at upcoming events, and experiencing a high level of stress when healthy foods are not available. The obsession with healthfulness comes with a high social cost as it is often difficult to enjoy eating out or sharing meals with friends and family. There is no formal treatment plan for orthorexia, but many eating disorder experts treat it similarly to anorexia and obsessive-compulsive disorder.[19]

Bigorexia Nervosa

Bigorexia nervosa, also known as muscle dysmorphia, is a subtype of body dysmorphic disorder in which individuals — most

commonly adolescent boys and young men — become preoccupied with the belief that they are insufficiently muscular, even when they have above-average strength or muscle mass. Clinically, bigorexia is characterized by compulsive exercise; rigid or "bulking" dietary regimens; excessive use of protein supplements or performance-enhancing substances; and significant distress or social impairment when workouts or eating routines are disrupted. Research led by Dr. Jason Nagata at the University of California, San Francisco, along with work by other leading scholars in adolescent health and eating disorders, has highlighted how cultural pressures — such as idealized superhero physiques, appearance-driven social media content, and expectations within competitive sports — intensify boys' drive for muscularity. These themes are explored in this accompanying video, "Understanding Eating Disorders in Boys: Insights from Dr. Jason Nagata", which examines how adolescent boys experience body ideals, the influence of sports culture, and early warning signs for parents. Emerging research also underscores that muscularity-oriented body concerns affect diverse groups, and may go unrecognized because eating disorders are often stereotyped as conditions that primarily affect girls. Recognizing the warning signs — rigid eating habits, compulsive training, withdrawal from social activities, or anxiety about body size — is critical for early identification and treatment.

Other Specified Feeding and Eating Disorders (OSFED)

What is Other Specified Feeding and Eating Disorders (OSFED)? People with OSFED experience eating disorder behaviors or outcomes that do not fit neatly into the other categories. OSFED can look very similar to the other disorders, or can be a very specific type of behavior that has just not been given its own clinical diagnosis yet.

OSFED may include:

- Restricting intake, but not meeting all the diagnostic criteria for anorexia nervosa
- Binging and purging, but not frequently enough to meet the diagnostic criteria for bulimia nervosa
- Binge eating, but not frequently enough to meet the diagnostic criteria for binge eating disorder
- Orthorexia nervosa (covered earlier); eating only what the person deems to be "healthy," which can be anything from a fixation on local/organic food, to vegan/vegetarian for the reason of trying to manipulate their body, to eating only certain kinds of foods/being obsessed with macronutrients
- Night-eating; which is waking in the night to eat when not physically hungry, on a regular basis
- Sleep-related eating disorder; when the person is sleep-walking and eating unaware they are doing so
- Diabulimia; people with type-1 diabetes dangerously manipulating insulin to lose weight. This leads to diabetic ketoacidosis
- Drunkorexia; "saving" calories for alcohol
- Pregorexia; restricting intake when pregnant to avoid weight gain
- Chewing and spitting out food
- ...and many other eating behaviors

OSFED is just as serious as the other eating disorders, though many health care providers may miss diagnosing it, as they are not as clear-cut as the other disorders.

Resources

If you think you or someone close to you may have an eating disorder and you want to learn more or find help, we've provided links to more resources below. Note that there are several other types of eating disorders not covered here, so if you're struggling with your relationship with food but your experience doesn't match one of the disorders described above, it may still be worth learning more and speaking with a professional to seek help.

- The National Eating Disorder Association offers many resources, including a short online screening tool that "can help determine if it's time to seek professional help."
- ANAD is a nonprofit providing free support services, including a helpline, recovery mentorship, and support groups, to anyone struggling with an eating disorder, disordered eating, and body image.
- Project HEAL is a nonprofit that offers free, 1-hour phone assessments for eating disorders, as well as free and sliding scale treatment, with a focus on increasing access for people identifying as BIPOC, LGBTQ+, and from other marginalized communities.

Self-Check:

Query 8.5.1

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8.6: Complex Causes of Excess Weight

Since the 1980s, the prevalence of obesity (defined as BMI of 30 or greater) in the United States has increased dramatically. Data collected by the Centers for Disease Control and Prevention show rising rates of obesity across the nation, state-by-state.[1]

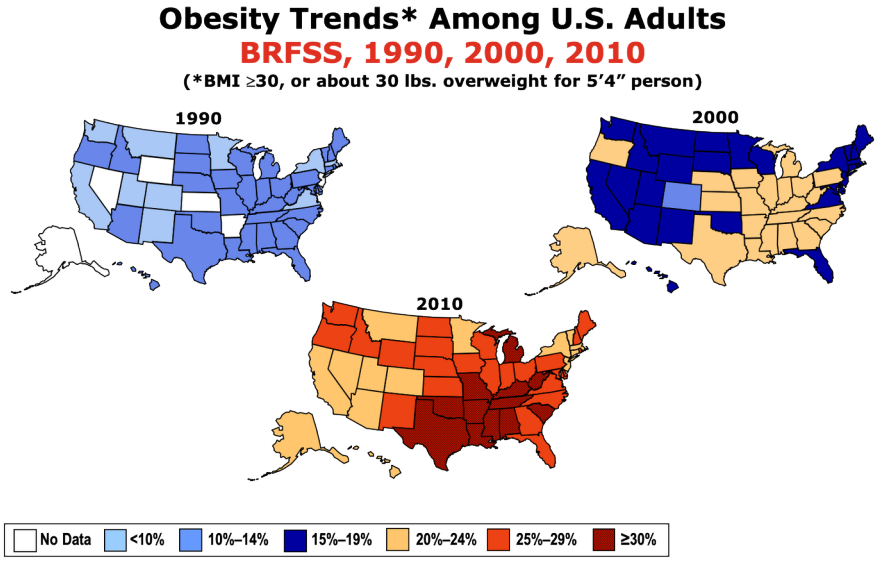
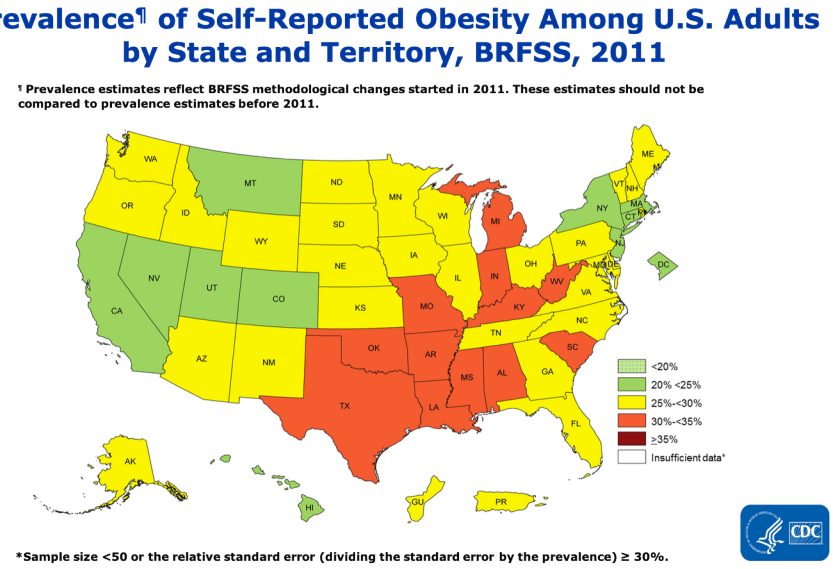


Figure 7.17. Each year since 1990, the CDC has published maps of the United States in which states are color-coded based on the percentage of their population estimated to be obese. The maps show a clear increase in the prevalence of obesity between 1990 and 2010.

The methods used by the CDC to collect the data changed in 2011, so we can't make direct comparisons between the periods before and after that change, but the trend has continued. Every year, more and more people in the U.S. report having a BMI that classifies them as having obesity, a trend that public health officials have labeled the obesity epidemic.



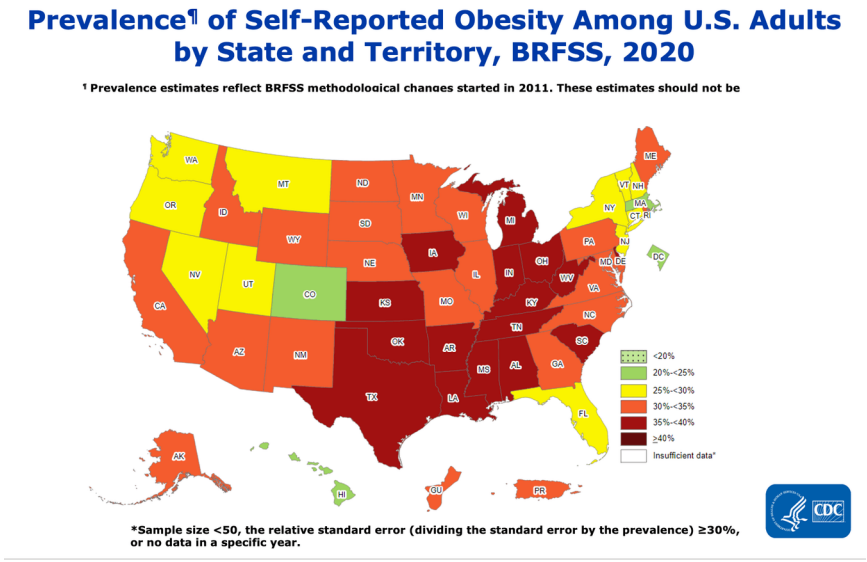


Figure 7.18. The prevalence of obesity among U.S. adults has continued to rise between 2011 and 2020.

These trends are unmistakable, and they're not just occurring in adults. Childhood obesity has seen similar increases over the last few decades. This is a concern because the metabolic and health effects of carrying too much weight can be compounded over a person's lifetime, and people with obesity in childhood are more likely to also have obesity as adults.[2]

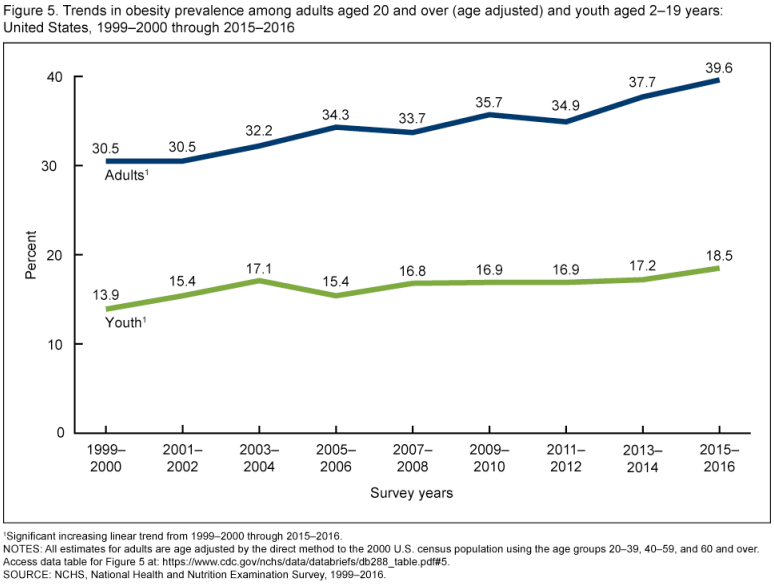


Figure 7.19. Between 1999 and 2016, the prevalence of obesity in both children and adults has risen steadily.

While obesity is a problem across the United States, it affects some groups of people more than others. Based on 2017-2018 data, **the prevalence of obesity is 50 percent among Black adults, 45 percent among Hispanic adults, 42 percent among white adults, and 17 percent among Asian adults in the U.S.** Overall, people who are college-educated and have a higher income are less likely to be obese.[3] These health disparities point to the importance of looking at social determinants of health when examining causes and solutions. Not everyone has the same opportunity for good health, or an equal ability to make changes to their circumstances, because of factors like poverty and longstanding inequities in how resources are invested in communities.[4]

In addition to the health issues that can be associated with obesity, excess weight is also associated with greater costs of medical care. Cost estimates vary widely, in part because it's very difficult to tease out health issues caused by obesity versus

those correlated with it. A 2016 review of studies found that, on average, a person with obesity had $1,901 greater medical costs than a person classified as normal weight, adding up to $149 billion in the United States.[5] A 2021 study reported similar cost estimates.[6] The obesity epidemic is also not unique to the United States. Obesity is rising around the globe, and in 2015, it was estimated to affect 2 billion people worldwide, making it one of the largest factors affecting poor health in most countries.[7] Previously, overweight and obesity mainly affected high-income countries, but some of the most dramatic increases in childhood overweight over the last decade have been in low income countries, such as those in Africa and South Asia.

Despite the gravity of the problem, **no country has yet been able to implement policies that have reversed the trend and brought about a decrease in obesity.** This represents "one of the biggest population health failures of our time," wrote an international group of researchers in the journal The Lancet in 2019.[9] Turning the tide will require an understanding of the complex causes of the rise in excess weight. As we'll see, these are interwoven into our environments, economies, societies, and policies, and we can thus assume that effective solutions will need to go far beyond the simplistic advice that people should "eat less and move more."

Possible Causes of Excess Weight

What has caused the rise in obesity around the world? This question is still an active area of debate among researchers. The predominant explanation comes back to the concept of energy balance: A chronic shift towards positive energy balance—consuming more energy or calories than expended—has led to a gradual but persistent increase in body weight. This shift is thought to be the result of changes in the environments in which we live, which include fewer opportunities for physical activity and greater availability and marketing of inexpensive, convenient, energy-dense foods.[10]

Putting the focus on energy balance often leads people to assume that obesity is an individual problem—that those who weigh more simply need to change their behavior to eat less and exercise more, and if this doesn't work, it must be because of a personal failing, such as a lack of self-control or motivation. However, science tells us that the reality is far more complex. Many factors can contribute to energy balance, and neurological and hormonal control of food intake and energy expenditure mean that it's difficult to maintain a negative energy balance and weight loss. Some researchers also argue that food intake and physical activity can't explain the continued increase in body weight, and we need to look to alternative explanations.[11] In the sections below, we discuss some of the hypothesized causes for the rise in obesity, acknowledging there are likely multiple causes to this complex issue.

Environment and Physical Activity

Many of us live in what researchers and public health experts call "obesogenic environments." That is, the ways in which our neighborhoods are built and our lives are structured influence our physical activity and food intake to encourage weight gain.[12] Human physiology and metabolism evolved in a world where obtaining enough food for survival required significant energy investment in hunting or gathering—very different from today's world where more people earn their living in sedentary occupations. From household chores, to workplace productivity, to daily transportation, getting things done requires fewer calories than it did in past generations.



Figure 7.20. Some elements of our environment that may make it easier to gain weight include sedentary jobs, easy access to inexpensive calories, and cities built more for car travel than for physical activity.

Our jobs have become more and more sedentary, with fewer opportunities for non-exercise thermogenesis (NEAT) throughout the

day. There's less time in the school day for recess and physical activity, and lack of neighborhood safety can limit kids' ability to get out and play after the school day is over. Our towns and cities are built more for cars than for walking or biking. We can't turn back the clock on human progress, and finding ways to stay active in modern environments is a significant challenge.

That said, recent research has called into question the role of physical activity in driving the rise in obesity. Studies of modern hunter-gatherer societies on the savannas of Africa have found that these very active people burn a similar number of calories each day as adults living more sedentary lifestyles in modern cities.[13] In addition, even as rates of obesity have continued to increase, research suggests that physical activity among U.S. adults has also been increasing.[11] Also, some studies find that people with higher BMI are more physically active than those in the normal weight category. "These findings contrast with conventional views that primarily attribute the cause of obesity to sedentary lifestyles and suggest that compensatory metabolic adaptations maintain total energy expenditure relatively constant among human populations and across various levels of physical activities," write the authors of the Joint International Consensus Statement for Ending Stigma of Obesity.[14] **Being physically active benefits our health in a multitude of ways, including preventing chronic diseases often associated with higher body weight, but it's not clear how much moving more affects long term energy balance or weight.**

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VIDEO: This short video explains some of the research on NEAT and efforts to increase it in our lives. James Levine: 'I Came Alive as a Person' (3 min), NOVA's Secret Life of Scientists and Engineers, https://youtu.be/fLgGf0BO4tw.

Food Intake and Diet Quality

Our environments can also impact our food choices. We're surrounded by vending machines, fast food restaurants, coffeeshops, and convenience stores that offer quick and inexpensive access to calories. These foods are also heavily advertised, and especially when people are stretched thin by working long hours or multiple jobs, they can be a welcome convenience. However, they tend to be more calorie-dense (and less nutrient-dense) and more heavily processed compared with home-cooked food. In addition, portion sizes at restaurants, especially fast food chains, have increased over the decades, and people are eating at restaurants more and cooking at home less. A randomized controlled trial found that participants had a greater caloric intake when eating processed foods compared with unprocessed foods, and eating more fruits and vegetables and less processed foods has been shown to be associated with less weight gain over time.[10,15]

Social Determinants of Health

As mentioned earlier in this unit, social determinants of health are the conditions in the places where people live, learn, work, and play that can affect health. They include factors related to socioeconomic instability, education, healthcare access and quality, neighborhood and built environment, and social and community context.[4] In the United States, people with more disadvantaged social determinants of health have a greater incidence of obesity, emphasizing the importance of addressing systemic inequities to improve health of all Americans.[16]

Social determinants such as poverty and socioeconomic instability decrease opportunities for health in many ways. People living in poorer neighborhoods often lack grocery stores where they can purchase fresh fruits and vegetables and basic ingredients for cooking at home. Such areas are called food deserts—where healthy foods simply aren't available or easily accessible. In these neighborhoods, people rely more on packaged and convenience foods that are more highly processed and may lead to greater energy intake.

People living with lower and less stable incomes also have to contend with food insecurity. Food security means "access by all people at all times to enough food for an active, healthy life."[16] Food insecurity means an inability to consistently obtain adequate

food. It may seem counter-intuitive, but in the United States, food insecurity is linked to obesity. That is, people who have difficulty obtaining enough food are more likely to become obese and to suffer from diabetes and hypertension. This is likely related to the fact that inexpensive foods tend to be high in calories but low in nutrients, and when these foods form the foundation of a person's diet, they can cause both obesity and nutrient deficiencies. It's estimated that 12 percent of U.S. households are food insecure, and food insecurity is higher among Black (22 percent) and Latino (18 percent) households.[17]

Poor neighborhoods are also sometimes not safe or pleasant places to walk, play, or exercise. They may have busy traffic and polluted air, and they may lack sidewalks, green spaces, and playgrounds. A person living in this type of neighborhood will find it much more challenging to incorporate physical activity into their day compared with someone living in a neighborhood where it's safe to walk to school or work, play at a park, ride a bike, or go for a run.

Social determinants of health likely drive and compound the racial and ethnic differences in obesity prevalence. Studies show that U.S. regions with more racial inequality in poverty, unemployment, and homeownership—all factors driven by historic and present-day inequities—have greater rates of obesity. In addition, experiencing racism and bias results in chronic stress, which is associated with greater weight gain.[18-19]

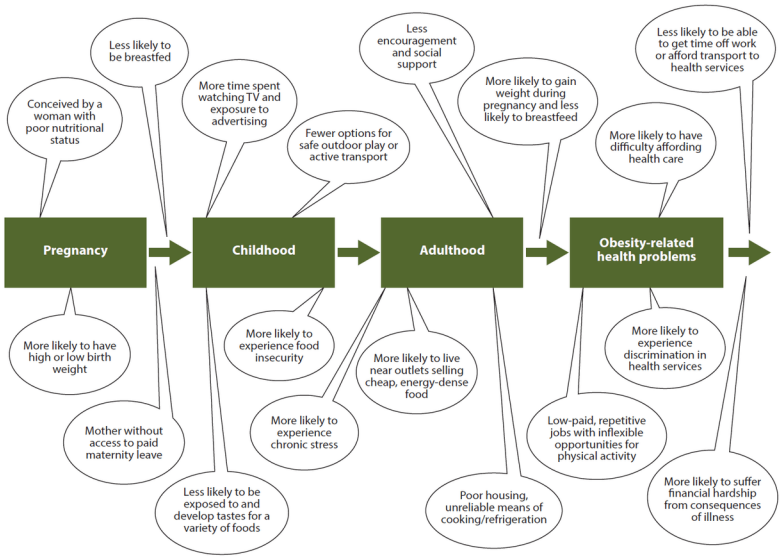


Figure 7.21. Social and economic inequities result in accumulated conditions that can increase risk of obesity and other health conditions.[19]

Genetics

What about genetics? While it's true that our genes can influence our susceptibility to weight gain, researchers say genes can't be the sole cause of the increasing prevalence of obesity. Genes take many generations to evolve, and the rise in obesity has occurred over just the last 40 to 50 years—only a few generations. When our grandparents were children, they were much less likely to become obese than our own children. That's not because their genes were different, but more likely because they grew up in different conditions. However, it is true that a person's genes can influence their susceptibility to weight gain in this environment, and obesity is more prevalent in some families. Research shows that about 50 to 75 percent of the variation in BMI is explained by genetic makeup.[10]

Dieting and Weight Stigma

We live in a society saturated by diet culture: Beliefs continuously promoted by diet companies, media, and influencers that center the idea that being thin is the same as being healthy, and that anyone who applies themselves by eating the right foods in the right amounts can achieve that ideal. But ironically, diet culture may contribute to weight gain. Studies show that dieting during adolescence is associated with greater risk of becoming overweight and of developing an eating disorder.[20] Having a greater

"drive for thinness" in adolescence is associated with similar attitudes and weight gain in adulthood.[21] There's also some research that finds that experiencing cycles of weight loss and weight regain (i.e., weight cycling or "yo-yo dieting") may cause people to gain even more weight over time, although the evidence on this point is somewhat mixed and controversial.[22,23]

In addition, living in a larger body and experiencing weight stigma, which has been shown to affect people at home, in social settings, in the workplace, and in healthcare settings, may also contribute to weight gain. **Experiencing weight stigma is associated with greater stress, less access to healthcare, less physical activity, and greater weight gain.**[24]

Other Possible Causes

Many other possible causes of weight gain have been investigated and likely contribute on some level to the increasing prevalence of obesity:

- Many **medications** that may improve our health are also known to cause weight gain. These include some medications used to treat common conditions such as diabetes, hypertension, autoimmune disorders, and depression.[14]
- Greater exposure to **endocrine disrupting chemicals**, such as those found in food packaging and pollutants, is associated with weight gain.[14]
- Not getting enough **sleep** or being under **greater stress** is associated with weight gain.
- Changes in the **gut microbiome** (the bacteria living in our gastrointestinal tract), caused by changing dietary patterns and environmental exposures to microbes, may predispose people to weight gain.[11]
- Having had **adverse childhood experiences (ACEs)**, defined as intensive stressors and traumatic events occuring in the first 18 years of life, is associated with a greater risk of obesity in adolescence and adulthood. ACEs include "recurring childhood maltreatment (physical, emotional and sexual abuse, and neglect), household dysfunction (witnessing violence between parents or caregivers, parental separation, incarceration or substance abuse of a household member, mental illness, and attempted or complete suicide by a family member), and community violence that deprive the sense of stability, safety and development of a child." Experiencing ACEs can cause changes in the brain, hormone levels, inflammation, sleep quality, and immune function, all of which can affect a person's risk of developing obesity.[25]

VIDEO: These segments from the HBO documentary series, "The Weight of the Nation," explore some of the causes and potential solutions for obesity. The Weight of the Nation: Poverty and Obesity (24 min) https://youtu.be/7MJnm5X9NN0 and The Weight of the Nation: Healthy Foods and Obesity Prevention (31 min)

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- Fig 7.17. "Obesity Trends Among U.S. Adults, BRFSS, 1990-2010" by Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention is in the Public Domain
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8.7: Solutions for Improving Health

According to a 2019 study, 42 percent of adults in the United States had recently attempted to lose weight, primarily through reduced food consumption and exercise.[1] This is not a surprise, given the growing prevalence of obesity and the constant messages of diet culture, which promote thinness as being equivalent to wellness and the latest diet fads as the keys to unlocking good health.

But, as we have learned, the causes of obesity are complex and interwoven into our society, and solutions for improving health will need to be equally far-reaching, going beyond individual efforts at weight loss. On this page, we look at potential solutions to health concerns related to body weight, both at the population and individual level.



Population Level Solutions

Because obesity can affect people over the course of their lifespan and is difficult to reverse, the focus of many of these efforts is on prevention, starting as early as the first years of life. Here, we'll review some strategies happening in schools, communities, and at state and federal levels.

Focus on Health Equity

Social determinants of health have a strong impact on obesity risk, so prevention efforts understandably target areas such as access to healthy foods and safe and affordable opportunities for physical activity. These are important, but fully addressing them will likely require societies to dig deeper into the root causes of existing disparities, to look at how factors such as poverty, racism, and discrimination affect people's opportunities for health. This means looking at how communities and governments can work toward ***health equity***, defined as "the fair and just opportunity for all to be as healthy as possible," requiring removal of obstacles to health such as poverty, discrimination, and their consequences.[2]

Consider low income neighborhoods that lack grocery stores, leaving residents without access to fresh foods and cooking ingredients. Policies and programs that bring groceries into these neighborhoods are important, but they may not do much to improve the nutrition or the food security of residents if they can't afford to shop there or have no time to cook because they need to work multiple jobs to support their families. Likewise, programs that give children bicycles or teach them about the importance of physical activity may not have an impact if there are no safe places to ride a bike or play in their neighborhood. Looking at this issue through the lens of health equity means tackling even bigger issues of poverty and access to education, resources, and safety. In this sense, policies and programs at community, state, and national levels that seek to improve people's lives by reducing income inequality and improving access to resources can help to target some of the core causes of obesity in

populations.[3]



An example of community-based interventions that aim to reduce health disparities can be found in the Racial and Ethnic Approaches to Community Health across the United States (REACH US) project, launched by the CDC in 2007. REACH US invested in many projects across the U.S., including 14 projects in predominantly Black communities aiming to reduce cardiovascular disease or diabetes. Each community project was unique and depended on local needs and preferences, but all included community coalitions, involving local leaders and residents, and targeted access to healthy food and/or improving physical activity opportunities. Between 2009 and 2012, the prevalence of obesity in REACH US communities dropped by 5 percent, while it increased by 2 percent in nearby comparison communities without a REACH program.[4]

End Weight Stigma

Weight stigma is a significant barrier to health, particularly for people living in larger bodies. It is harmful to both mental and physical health and counter-productive to the goal of reducing obesity and improving health. The following is the executive summary of the Joint International Consensus Statement for Ending Stigma of Obesity[5]:

- Weight stigma is reinforced by misconceived ideas about body-weight regulation and lack of awareness of current scientific evidence. Weight stigma is unacceptable in modern societies, as it undermines human rights, social rights, and the health of afflicted individuals.
- Research indicates that weight stigma can cause significant harm to affected individuals. Individuals who experience it suffer from both physical and psychological consequences, and are less likely to seek and receive adequate healthcare.
- Despite scientific evidence to the contrary, the prevailing view in society is that obesity is a choice that can be reversed by voluntary decisions to eat less and exercise more. These assumptions mislead public health policies, confuse messages in popular media, undermine access to evidence-based treatments, and compromise advances in research.
- For the reasons above, weight stigma represents a major obstacle in efforts to effectively prevent and treat obesity and type 2 diabetes. Tackling stigma is not only a matter of human rights and social justice, but also a way to advance prevention and treatment of these diseases.
- Academic institutions, professional organizations, media, public health authorities, and government should encourage education about weight stigma and facilitate a new public narrative of obesity, coherent with modern scientific knowledge.

Support Healthy Dietary Patterns

Interventions that support healthy dietary patterns, especially among people more vulnerable because of food insecurity or poverty, may reduce obesity. Here are some examples:

- **Implement and support better nutrition standards for childcare, schools, hospitals, and worksites.** The National School Lunch Program in particular provides meals for approximately 30 million children from low-income families each

school day, and recent changes in school lunch standards have improved dietary quality for students consuming school lunches.[3,6]

- **Limit or end marketing of processed foods and sugar sweetened beverages**, especially ads that disproportionately target children of color.[7]
- **Provide incentives for supermarkets and farmers markets** to establish businesses in underserved areas.[7]



Figure 7.22. Farmers markets can expand healthy food options for neighborhoods and build connections between consumers and local farmers.

- **Increase access to food assistance programs and align them with nutrition recommendations.** For example, in 2009, the U.S. Department of Agriculture revised the food packages for the Women, Infants, and Children (WIC) program to better align with the Dietary Guidelines for Americans. The new packages emphasized more fruits, vegetables, whole grains, and low-fat dairy and decreased the availability of juice. After this change, between 2010 and 2016, there was a decrease in the obesity rate of children in the WIC program.[8] Similar progress may be made by increasing access to the Supplemental Nutrition Assistance Program (SNAP) in order to reduce food insecurity, and providing incentives to use SNAP benefits on foods like fruits and vegetables. Many farmers' markets now accept SNAP benefits for the purchase of fresh fruit and vegetables.[7]
- **Tax sugary drinks, such as soda and sports drinks**, which contribute significant empty calories to the U.S. diet and are associated with childhood obesity. Local taxes on soda and other sugary drinks are often controversial, and soda companies lobby to prevent them from passing. However, research from U.S. cities with soda taxes show that they do work to decrease soda consumption, and one study concluded that a national soda tax may be the most cost-effective obesity prevention measure, estimating that it could prevent more than 500,000 cases of childhood obesity over 10 years.[7] In the U.S., soda has only been taxed at the local level, and the tax has been paid by consumers. The United Kingdom has taken a different approach: They started taxing soft drink manufacturers for the sugar content of the products they sell. Between 2015 and 2018, the average sugar content of soda sold in the U.K. dropped by 29 percent.[9]
- **A controversial policy intervention has been the requirement that restaurant menus include calorie information.** Beginning in 2018, as part of the Affordable Care Act, chain restaurants in the U.S. with more than 20 locations were required to add calorie information to their menus, and some had already done so voluntarily. Overall, the research on menu labeling has shown it may slightly reduce the calorie count of restaurant purchases, but it doesn't seem to reduce calories consumed in a sitting, and there's no evidence that menu labeling affects total calories consumed in the long term, dietary quality, or risk of obesity.[10]



Figure 7.23. As of 2018, restaurant chains and some other food vendors are required to list calorie counts on their menus. Would these make you pause before ordering?

Support Greater Physical Activity

Physical activity can help maintain energy balance and promote health in many ways, including preventing chronic diseases often associated with higher body weight. The CDC recommends several evidence-based strategies to increase physical activity in communities[12,13]:

- **Activity-friendly routes to everyday destinations** – This strategy focuses on creating easier, more appealing, and more accessible opportunities for everyday physical activity within the community. It includes adding sidewalks, bike lanes and paths, hiking trails, and public transit to connect homes, schools, green spaces, parks, worksites, stores, restaurants, and libraries. This infrastructure allows for more physical activity throughout the day.
- **Access to places for physical activity** – This strategy provides more access (free or reduced-cost) to spaces for physical activity, such as parks, recreation centers, and gyms. It includes workplaces that provide gym facilities and/or time off during the day for physical activity.
- **School and youth programs** – This includes providing physical activity programs in schools, enhancing physical activity during recess periods, and before- and after-school activities, such as sports and activity clubs.
- **Community-wide campaigns** – These programs encourage community-wide participation in physical activity through the use of media coverage and promotion, community events, classes, contests, and educational opportunities.
- **Social supports** – This strategy focuses on building social groups centered on physical activity, such as through walking, cycling, or hiking clubs.
- **Individual supports** – Worksites, schools, organizations, and churches can offer individuals support in the form of education and counseling to build skills and set activity goals.
- **Prompts to encourage physical activity** – These include elements such as signs that encourage taking the stairs over using an elevator or choosing walking and biking routes through neighborhoods.



Figure 7.24. There are many ways to increase physical activity, including walking to work, playing with friends, and going for a bike ride.

Individual Level Solutions

While we acknowledge that population level solutions are likely most important for improving the health of communities, we know that individuals may also be concerned about their weight or health. For people who believe that their weight is affecting their health or quality of life, what steps can they take? There is no one-size-fits-all approach. In this section, we'll discuss lifestyle changes that can improve health (whether or not they result in weight loss), the evidence for weight loss diets, weight loss medications, bariatric surgery, and non-diet approaches.

Biology of Weight Loss and Maintenance

As we discussed earlier in this unit, energy balance determines whether we are gaining, losing, or maintaining body weight. To lose weight, we need to shift into a negative energy balance, so that we are consuming fewer calories than we are burning each day. Most people find that they are able to do this by restricting their calorie or macronutrient intake (i.e., dieting) for a short period of time, perhaps 6 months or a year, and they may lose 5 to 10 percent of their body weight. However, it is very common for people to experience gradual weight regain within a year or two. This fact is what fuels the diet industry; diet companies market their plans based on short-term success stories and frame the longer term reality of weight regain as personal failing or lack of willpower. Even scientific studies of weight loss rarely follow people for more than 12 months, which can lead to reporting of overly optimistic results.[14,15]

Why is it so difficult to maintain a reduced body weight? Keep in mind that weight, like so many other parts of our physiology, is tightly regulated. Our bodies can make adjustments to both sides of the energy balance equation to help us maintain a steady weight. During periods of negative energy balance, the body signals weight loss as a threat to survival, and these regulatory mechanisms kick in to defend the original weight. Basal metabolic rate drops to conserve energy and protect against starvation. Skeletal muscles also become more efficient, so that they need less energy to fuel their movement. Additionally, after weight loss, there is less physical mass of the body that has to be moved from place to place throughout the day, resulting in fewer calories burned through physical movement and activity, and less metabolically active tissue using calories for fuel throughout the day. These metabolic changes conserve energy, reducing the "energy out" side of the energy balance equation and favoring weight regain.[16,17] In individuals maintaining a 10% or greater weight loss, these changes combine to account for an estimated decrease of 300-400 calories in energy expenditure per day beyond what is expected due to the change in body composition alone.[18]

On the "energy in" side of the equation, neurological and hormonal changes also increase appetite, lower satiety, and increase the brain's focus on obtaining food. Researchers have estimated that weight loss of about 2 pounds increases appetite by about 95 calories per day.[16,17] These biological factors and their influence on weight are discussed further in the video below.

YouTube Video

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View this YouTube Video online

VIDEO: "The Quest to Understand the Biology of Weight Loss," by HBO Docs, YouTube (May 14, 2012), 22:52 minutes.

Biological differences in individual metabolism may also impact weight loss and maintenance. Researchers have found that some individuals have a "thrifty" metabolism, meaning that they have a lower metabolic rate and will expend significantly fewer calories when in a fasting or calorie-restricted state, resulting in less weight loss. In contrast, individuals with a "spendthrift" metabolism tend to have a higher metabolic rate in a fasting state, burning more calories and thus yielding bigger weight loss results.[19] This research explains why some people may be able to lose weight and maintain weight loss, while others will struggle to do so, even with substantial effort.

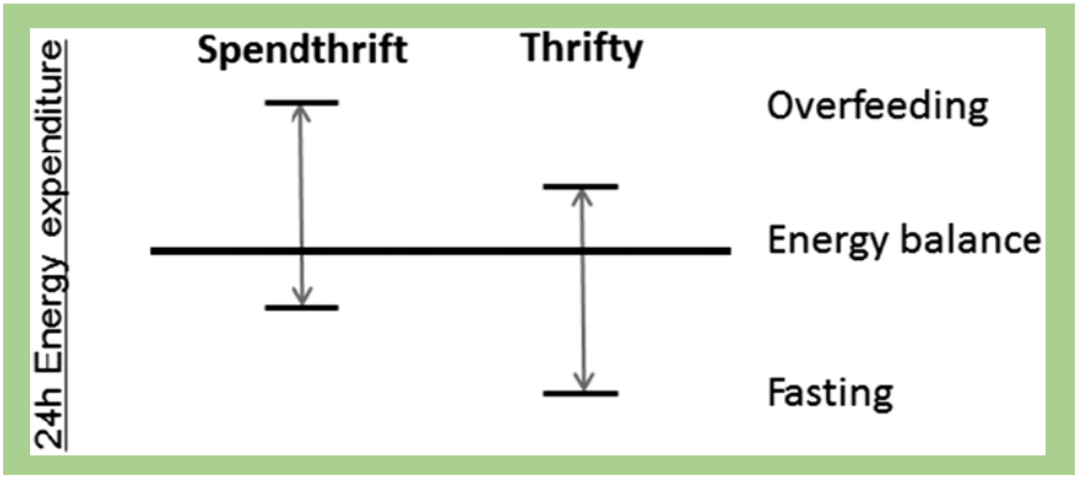


Figure 7.25. Illustration of the concept of spendthrift and thrifty metabolism, characterized by response to overfeeding and fasting.

Setting Goals and Expectations

It's clear that sustained weight loss is difficult and complex. But weight loss doesn't need to be the primary goal to improve health. There are many ways to improve your health that aren't tied to changing your weight or BMI. If you're at a higher weight and concerned about your weight or health, a good starting point may be thinking of steps you can take to improve your health that are in your immediate control. For example, are you getting enough sleep? What strategies can you take to reduce your stress level? How can you improve your eating habits to better nourish your body? Can you incorporate more enjoyable forms of physical activity into your daily routine? **Setting goals around behavior and health rather than a number on the scale improves your likelihood of feeling successful and making sustainable changes.** And since many of these daily habits are also thought to affect weight, making positive changes may (but may not) lead to some weight loss. In addition, talk with your doctor about any medications you are using that could cause weight gain.

If weight loss is one of your goals, it's important to have realistic expectations. The goal of weight loss efforts should be to "prevent, treat, or reverse the complications of obesity and improve the quality of life."[20] Specific goals and approaches will look different for everyone depending on their individual risk factors and lifestyle. Research shows that losing just 5 percent of body

weight is associated with significant health benefits such as lower blood pressure and improved blood cholesterol levels, and changing diet or exercise habits typically can reduce body weight by about 5 to 7 percent.[20] However, many people set weight loss goals well beyond this mark, leading to disappointment and frustration if they fall short. It may be helpful to set a goal of reaching your "best weight," defined in the 2020 Canadian Adult Obesity Clinical Practice Guidelines as "the weight that a person can achieve and maintain while living their healthiest and happiest life."[21]

Even more difficult than losing weight is maintaining a reduced weight. Weight regain is common, so at the outset, it's important to think about how weight loss strategies can be sustained for the long term. Weight control registries from around the world have tracked thousands of people who have successfully lost weight and maintained a reduced weight over time. While these registries include self-selected samples and thus are not representative of all people attempting weight loss, their findings provide some examples of the types of habits associated with maintaining individual weight loss. For example, more than 80 percent of global registry members report consuming breakfast daily, increasing their consumption of vegetables and high fiber foods, eating regular meals, watching their consumption of foods higher in fat and sugar, and keeping healthy foods on hand at home. Physical activity is also an important part of their ongoing efforts; most registry members reported exercising regularly, many for about an hour per day.[22]

Evidence-Based Dietary Approaches

There are many dietary approaches to weight loss, and research shows that there is no single dietary strategy that is superior to others. Dietary approaches that have been shown to be effective, at least in the short-term, include the Mediterranean diet, the Dietary Approaches to Stop Hypertension (DASH) eating plan, vegetarian diet, and a variety of lower-calorie macronutrient distribution diets, such as low-fat and low- carbohydrate approaches.[14]

While not specifically about weight loss, the 2020 Dietary Guidelines for Americans also offers specific, evidence-based recommendations for dietary habits that provide a good roadmap for healthy eating. These guidelines are aimed at keeping calorie intake in balance with physical activity, which is key for weight management. These recommendations include following a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level. Chapter 1: Tools for Achieving a Healthy Diet includes a more detailed look at these guidelines.

Most Americans do not meet the recommendations of the Dietary Guidelines, indicating room for improvement in dietary quality. Figure 7.26 shows how Americans are falling short of meeting the recommendations for vegetables, fruit, whole grains, dairy, and seafood and consume well over the recommended amount for refined grains. Meanwhile, many Americans also exceed the recommended limits for added sugars, saturated fats, sodium, and alcohol. Shifting towards more nutrient-dense choices, as recommended in the Dietary Guidelines, can help balance caloric intake and better meet nutrient needs for optimal health. In addition, evidence-based guidelines for obesity emphasize the importance of an individualized eating approach that is culturally acceptable, affordable, and prioritizes individual preferences to promote long-term adherence.[24]

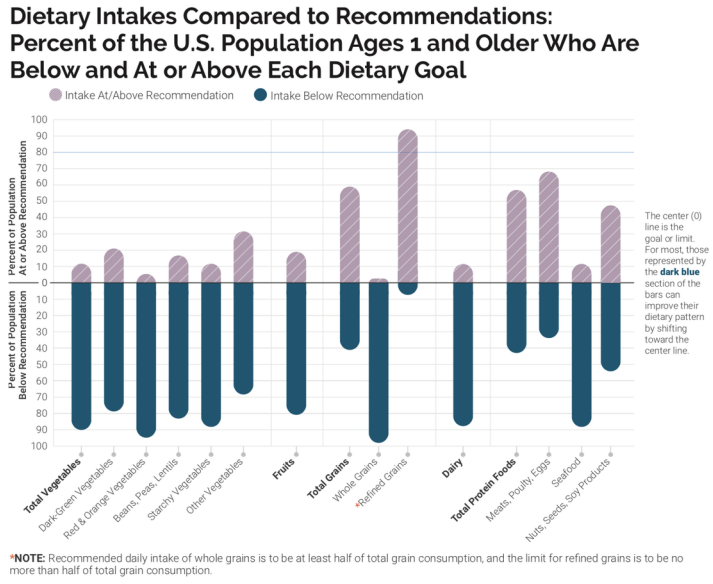


Figure 7.26. This graph indicates the percentage of the U.S. population ages 1 year and older with intakes below the recommendation or above the limit for different food groups and dietary components.

Evidence-Based Physical Activity Recommendations

The other part of the energy balance equation is physical activity. The 2018 Physical Activity Guidelines for Americans, issued by the Department of Health and Human Services (HHS) provide evidence-based guidelines for appropriate physical activity levels. These guidelines provide recommendations to Americans aged three and older about how to improve health and reduce chronic disease risk through physical activity. Increased physical activity has been found to lower the risk of heart disease, stroke, high blood pressure, Type 2 diabetes, some forms of cancer, falls and fractures, depression, and early death. Increased physical activity not only reduces disease risk but also improves overall health by increasing cardiovascular and muscular fitness, increasing bone density and strength, improving cognitive function, and assisting in weight loss and weight maintenance.[25] In addition, physical activity has been shown to improve mood disorders, body image, and overall health-related quality of life.[26] These benefits of physical activity can help counter some of the potential effects of carrying excess weight, and some research suggests that increasing physical activity and fitness levels is more effective than weight loss when it comes to reducing the risk of heart disease and premature death.[26] To be most effective, individuals should find activities they enjoy so they can sustain their activity level for lifelong health.[27]

Key guidelines for physical activity are summarized in Chapter 10: Essential Elements and Benefits of Physical Fitness, but a few worth mentioning specific to weight include the following:

- For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) per week of moderate-intensity aerobic activity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) per week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity.
- Engaging in physical activity beyond the equivalent of 300 minutes (5 hours) of moderate-intensity physical activity per week can result in additional health benefits and may help with weight loss and weight loss maintenance.
- Adults should also do muscle-strengthening activities of at least moderate intensity that involve all major muscle groups on 2 or more days per week, as these activities provide additional health benefits and promote weight maintenance. Exercises such as push-ups, sit-ups, squats, and lifting weights are all examples of muscle-strengthening activities.

Despite the indisputable benefits of regular physical activity, just 23 percent of Americans met the national physical activity guidelines in 2018, although this number has gradually increased over the last several decades.[28] Given the number of Americans that are falling short on both nutrition and physical activity recommendations, both of these areas are of primary interest in improving health in the United States.

Evidence-Based Behavioral Recommendations

Behavioral weight loss interventions have been described as approaches “used to help individuals develop a set of skills to achieve a healthier weight. It is more than helping people to decide what to change; it is helping them identify how to change.”[29] Cornerstones for these interventions typically include self-monitoring through daily recording of food intake and exercise, nutrition education and dietary changes, physical activity goals, and behavior modification.[30] Research shows that these types of interventions can result in weight loss and a lower risk for type 2 diabetes, and similar maintenance strategies lead to less weight regained later.[31]

Behavioral interventions have been shown to help individuals achieve and maintain weight loss of at least 5 percent from baseline weight. The Food and Drug Administration (FDA) considers a 5 percent weight loss to be clinically significant, as this level of weight loss has been shown to improve cardiometabolic risk factors such as blood lipid levels and insulin sensitivity.[32,33] The behavioral intervention team often includes primary care clinicians, dietitians, psychologists, behavioral therapists, exercise physiologists, and lifestyle coaches.[32] These programs may include a variety of delivery methods, often through group classes of 10-20 participants both in-person and online, and may use print-based or technology-based materials and resources. The interventions usually span one to two years with more frequent contact in the initial months (weekly to bi-monthly), followed by less frequent contact (monthly) in the latter months or maintenance phase.[32] A variety of behavioral topics are covered over the course of the program and range from nutrition education and goal-setting, to problem-solving and assertiveness. Relapse

prevention is included as participants move into the maintenance phase.[31]



Figure 7.27. Common topics included in behavioral interventions for weight loss, adapted from Smith, C. E., & Wing, R. R. (2000). New directions in behavioral weight-loss programs. Diabetes Spectrum, 13(3), 142-148.

One example of a comprehensive behavior intervention is the Diabetes Prevention Program (DPP). This was a high quality randomized controlled trial that enrolled participants at high risk for developing type 2 diabetes and included an intervention group that made dietary and physical activity changes with the support of frequent meetings with researchers to implement behavioral changes. In the DPP study, participants lost an average of 15 pounds and reduced their risk of developing type 2 diabetes by 58 percent in the first year. They gradually regained an average of 10 pounds by 10 years later. However, 10 years after the start of the study, intervention participants still had a 34 percent reduced risk in developing type 2 diabetes, indicating significant health benefits of the program.[33]

The DPP yielded such significant improvements in risk of developing diabetes that it was expanded to a national program available in communities throughout the U.S. To find a DPP intervention program near you, visit the National Diabetes Prevention Program website.

Pharmacotherapy and Bariatric Surgery

GLP-1 Medications

When lifestyle changes in diet, exercise, and behavior modification do not produce or sustain meaningful levels of weight loss, the use of medications may be considered to improve weight loss and health outcomes. While continuing with a healthy lifestyle, medications are typically considered for individuals with a BMI over 30, or BMI over 27 with at least one coexisting condition, such as heart disease, type 2 diabetes, or hypertension.

A newer class of weight loss medications known as glucagon-like peptide-1 (GLP-1) receptor agonists are a class of medications originally developed to manage type 2 diabetes that have since shown broad health benefits extending beyond glycemic control and weight loss. Commonly used GLP-1 medications include semaglutide (brand names *Ozempic, Wegovy*), liraglutide (*Saxenda, Victoza*), and tirzepatide (*Mounjaro*), a dual GIP/GLP-1 receptor agonist with similar mechanisms.

A dual GIP/GLP-1 receptor agonist is a type of medication that activates two different hormone receptors involved in regulating metabolism — the glucose-dependent insulinotropic polypeptide (GIP) receptor and the glucagon-like peptide-1 (GLP-1) receptor. These have been shown in clinical trials to provide superior glucose control and weight loss compared to GLP-1 receptor agonists alone. This combination approach takes advantage of the complementary mechanisms of the two hormones to improve metabolic health more effectively.

Here's what this means in simpler terms:

- GLP-1 and GIP are both hormones released from the gut after eating.
- They help stimulate insulin release, suppress glucagon, and regulate appetite and digestion — all of which help control blood sugar and body weight.
- A dual agonist activates both receptors at once, mimicking the action of both hormones, which may lead to greater therapeutic effects than targeting GLP-1 alone.

Research has demonstrated that GLP-1 therapies not only improve blood sugar regulation and promote significant weight reduction, but also reduce the risk of major adverse cardiovascular events, lower blood pressure, improve liver health (including in non-alcoholic fatty liver disease), and potentially protect cognitive function. At least one company is currently developing an oral form of GLP-1 therapy, known as *orforglipron*, which promises to offer similar metabolic benefits without the need for injections — potentially improving patient adherence, convenience, and accessibility.

As with many drugs used to treat chronic diseases, people generally need to continue using these medications for the long term to avoid weight regain. Additionally, these transformative treatments remain financially out of reach for many, especially low-income Americans who are disproportionately affected by diabetes, obesity, cardiovascular disease, and related conditions. Expanding availability and affordability of GLP-1 medications is a critical public health priority: addressing health disparities requires ensuring that those most in need — often facing systemic barriers to care — can access the same life-changing therapies as wealthier populations.

WHO global guideline on the use of GLP-1 medicines in treating obesity

To respond to the rapidly growing global burden of obesity — now affecting more than one billion people worldwide and linked to 3.7 million deaths in 2024 — the World Health Organization (WHO) has for the first time issued a clinical guideline endorsing GLP-1 therapies as a component of long-term care for obesity. World Health Organization+2Pan American Health Organization+2 In a landmark policy shift, obesity is now defined by WHO as a chronic, relapsing disease requiring sustained, lifelong care rather than a temporary condition. JAMA Network+1 In its guideline, WHO issues two conditional recommendations: first, that adults (excluding pregnant women) may receive GLP-1 therapies for long-term obesity treatment, recognizing that evidence of metabolic and clinical benefits is strong — albeit with limitations in data on long-term safety, maintenance, and access. JAMA Network+1 Second, for those prescribed GLP-1s, offering intensive behavioural interventions (structured diet, physical activity, counselling) may enhance outcomes and support sustainable weight management. JAMA Network+1

WHO emphasizes, however, that medication alone will not solve the obesity crisis. Instead, these drugs must be part of a broader, equitable, health-system–based “obesity ecosystem” that combines medical treatment with supportive environments, lifestyle interventions, early screening, prevention, and lifelong follow-up care. Pan American Health Organization+2nutritioninsight.com+2 WHO warns that without fair access strategies (such as pooled procurement, tiered pricing, licensing, and system readiness), the benefits of GLP-1 therapies may reach only a fraction of those in need — aggravating rather than reducing global health inequities. nutritioninsight.com+2Pan American Health Organization+2

You can read the full guideline here: **WHO guideline on the use of glucagon-like peptide-1 (GLP-1) therapies for the treatment of obesity in adults**.

Over-the-counter weight loss products

Most over-the-counter weight loss supplements are not monitored by the FDA and are not recommended due to safety concerns.[34,35]

Bariatric surgery

Surgical interventions may be appropriate for people with a BMI over 40 or BMI over 35 with obesity-related coexisting conditions, so long as they’re motivated to lose weight and behavioral interventions (with or without medication) have not been effective. Potential candidates for surgery should be referred to an experienced bariatric surgeon for consultation and evaluation.[20,34]

Non-Diet Approaches

In addition to weight management approaches that focus on dietary changes, physical activity programs, and behavioral interventions, there is a growing movement for non-diet approaches for a healthier mentality toward weight, food, and body image. These approaches focus on establishing healthier relationships with food and more body acceptance and positivity regardless of shape and size. They seek to normalize relationships with food, make eating an enjoyable experience focused on well-being rather than dieting, do away with shame or guilt often associated with failed weight loss efforts, and promote respect and inclusivity for all people regardless of weight or size. Mindful eating or intuitive eating are common components of these approaches. These non-diet approaches have been shown to improve quality of life, general well-being, body image, cardiovascular outcomes, physical activity, and eating behaviors regardless of changes in weight status.[24]



One of these non-diet approaches, the Satter Eating Competence Model, is based on four components: eating attitudes, food acceptance, regulation of food intake and body weight, and management of the eating context. According to Ellyn Satter, a registered dietitian, family therapist, and the founder of the model, competent eaters are "confident, comfortable, and flexible with eating and are matter-of-fact and reliable about getting enough to eat of enjoyable and nourishing food." This approach enhances "the importance of eating by making it positive, joyful, and intrinsically rewarding."[36] This model emphasizes that by developing a healthier relationship with food, individuals will yield the following benefits:[37]

- Have better diets
- Feel more positive about food and eating
- Have better overall health
- Have the same or lower BMI
- Sleep better
- Be more active
- Have better physical self-acceptance
- Be more trusting of themselves and others

Health at Every Size (HAES) is another non-diet movement started by the Association for Size Diversity and Health (ASDAH) organization as an alternative to weight-centered health models. HAES aims to decrease our culture's obsession with body size and weight, decrease weight discrimination and stigma, and instead promote size acceptance and inclusivity.[38] Key principles of the HAES approach include:

- Acceptance and respect for the inherent diversity of body shapes and sizes
- Health enhancement through policies and services that promote well-being in all aspects of health, including physical, economic, social, emotional, and spiritual needs
- Respectful care and elimination of weight bias and discrimination through proper education and training
- Eating behaviors driven by hunger, satiety, nutritional needs, and pleasure instead of external regulation by diets and eating

plans
- Physical activity through life-enhancing movement for all sizes and abilities

To learn more about non-dieting approaches for a healthy lifestyle, check out the following video.

Interactive Content

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View this Interactive Content online

VIDEO: "Why Dieting Doesn't Usually Work," from TED, 12:30 minutes.

It's clear that obesity is a complex disease that must be managed through a focus on overall health and well-being, not just by changing a number on the scale. Issues around weight bias and stigma must be addressed. Our current health system must improve to support individuals regardless of body shape and size. And current cultural narratives around obesity must change to remove assumptions of weakness or lack of willpower as causes of obesity and eliminate attitudes that cast blame and shame on people living with obesity.[24]

Self-Check:

Query 8.7.1

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CHAPTER 9: VITAMINS

Learning Objectives

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

- Describe the role of vitamins as antioxidants in the body
- Describe the functions and sources of antioxidant vitamins and phytochemicals
- Describe the functions of vitamins in catabolic pathways, anabolic pathways

9.1: Introduction to Micronutrients

9.2: Vitamins Overview and Introduction

9.3: Vitamins and Energy Metabolism — B1, B2, Niacin, Pantothenic Acid, Biotin and Choline

9.4: Vitamins and Healthy Blood — B6, Folate, B12, K

9.5: Antioxidant Vitamins — C and E

9.6: Vitamins and Gene Expression — A and D

9.7: Sources of Vitamins

9.8: Dietary Supplements

9.9: Phytochemicals

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9.1: Introduction to Micronutrients

Vitamins and minerals are micronutrients, and by definition, they make up a relatively small part of our diet. However, when it comes to vitamins and minerals, a little bit goes a long way. They have many essential jobs in our bodies.

For example, if you've taken a drink of water today, you can thank the minerals that serve as electrolytes, helping to balance fluids in the body. If you've taken a breath of air, you can thank the vitamins and minerals that act as antioxidants, protecting vital molecules from free radical damage. If you've taken a step, you can thank the vitamin D, calcium, and other minerals that make your bones strong. If you've moved a muscle, you can thank the many vitamins and minerals that serve as cofactors in metabolic reactions, which unlock the energy contained in nutrients so that your body can use it.



Figure 9.1.1: "assorted-color tomatoes" by Vince Lee on Unsplash (license information)

There are some 13 vitamins and 16 minerals important to human nutrition, and each serves multiple functions in the body. Entire books have been written about each one, and we could easily spend a whole term learning about all of these amazing nutrients. But as this is an introductory course, we'll use the next two units to introduce you to some of the most interesting vitamins and minerals, with a focus on those that are commonly limiting in the human diet.

We'll begin this chapter with a general introduction to vitamins and how they are classified (water-soluble vs. fat-soluble). Then, we'll cover the major functions of vitamins, where we find them in food, and what happens if we consume too little or too much of each. We will also consider the role of food, fortified foods, and dietary supplements in meeting our vitamin and mineral requirements.

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9.2: Vitamins Overview and Introduction

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



Vitamins

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

Classification of Vitamins

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

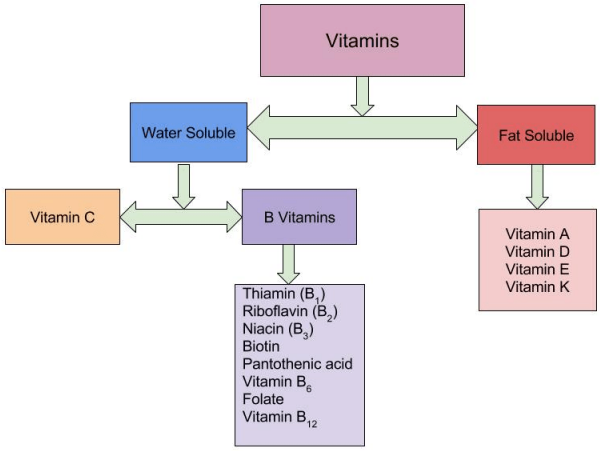


Figure 8.1. Classification of vitamins as water-soluble or fat-soluble.

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

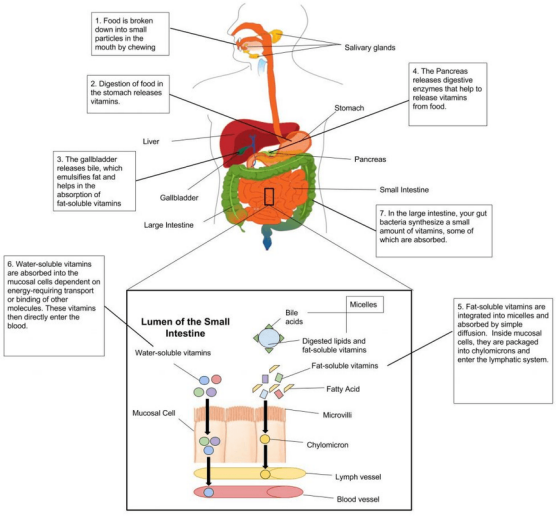


Figure 8.2. “Absorption of Fat-Soluble and Water-Soluble Vitamins.”

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

There is limited storage capacity in the body for water-soluble vitamins, thus making it important to consume these vitamins on a daily basis. Deficiency of water-soluble vitamins is more common than fat-soluble vitamin deficiency because of this lack of storage. That also means toxicity of water-soluble vitamins is rare. Because of their solubility in water, intake of these

vitamins in amounts above what is needed by the body can, to some extent, be excreted in the urine, leading to a lower risk of toxicity. Similar to fat-soluble vitamins, a toxic intake of water-soluble vitamins is not common through food sources, but is most frequently seen due to supplement use.

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

Table 8.1. Characteristics of fat-soluble and water-soluble vitamins.

Summary of Water-Soluble Vitamins

Table 9.2.19: Water-Soluble vitamins

Vitamin	Sources	Recommended Intake for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Vitamin C (ascorbic acid)	Orange juice, grapefruit juice, strawberries, tomato, sweet red pepper	75-90 mg/day	Antioxidant, collagen synthesis, hormone and neurotransmitter synthesis	Scurvy, bleeding gums, joint pain, poor wound healing,	Smokers, alcoholics, elderly	Kidney stones, GI distress, diarrhea	2000 mg/day
Thiamin (B1)	Pork, enriched and whole grains, fish, legumes	1.1-1.2 mg/day	Coenzyme: assists in glucose metabolism, RNA, DNA, and ATP synthesis	Beriberi: fatigue, confusion, movement impairment, swelling, heart failure	Alcoholics, older adults, eating disorders	None reported	ND

Vitamin	Sources	Recommended Intake for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	UL
Riboflavin (B2)	Beef liver, enriched breakfast cereals, yogurt, steak, mushrooms, almonds, eggs	1.1-1.3 mg/day	Coenzyme: assists in glucose, fat and carbohydrate metabolism, electron carrier, other B vitamins are dependent on	Ariboflavinosis: dry scaly skin, mouth inflammation and sores, sore throat, itchy eyes, light sensitivity	None	None reported	ND
Niacin (B3)	Meat, poultry, fish, peanuts, enriched grains	14-16 NE/day	Coenzyme: assists in glucose, fat, and protein metabolism, electron carrier	Pellagra: diarrhea, dermatitis, dementia, death	Alcoholics	Nausea, rash, tingling extremities	35 mg/day from fortified foods and supplements
Pantothenic Acid (B5)	Sunflower seeds, fish, dairy products, widespread in foods	5 mg/day	Coenzyme: assists in glucose, fat, and protein metabolism, cholesterol and neurotransmitter synthesis	Muscle numbness and pain, fatigue, irritability	Alcoholics	Fatigue, rash	ND
B6(Pyridoxine)	Meat, poultry, fish, legumes, nuts	1.3-1.7 mg/day	Coenzyme; assists in amino-acid synthesis, glycogneolysis, neurotransmitter and hemoglobin synthesis	Muscle weakness, dermatitis, mouth sores, fatigue, confusion	Alcoholics	Nerve damage	100 mg/day
Biotin	Egg yolks, fish, pork, nuts and seeds	30 mcg/day	Coenzyme; assists in glucose, fat, and protein metabolism, amino-acid synthesis	Muscle weakness, dermatitis, fatigue, hair loss	Those consuming raw egg whites	None reported	ND
Folate	Leafy green vegetables, enriched grains, orange juice	400 mcg/day	Coenzyme; amino acid synthesis, RNA, DNA, and red blood cell synthesis	Diarrhea, mouth sores, confusion, anemia, neural-tube defects	Pregnant women, alcoholics	Masks B12 deficiency	1000 mcg/day from fortified foods and supplements
B12(cobalamin)	Meats, poultry, fish	2.4 mcg/day	Coenzyme; fat and protein catabolism, folate function, red-blood-cell synthesis	Muscle weakness, sore tongue, anemia, nerve damage, neural-tube defects	Vegans, elderly	None reported	ND
Choline	Egg yolk, wheat, meat, fish, synthesis in the body	425-550 mg/day	Synthesis of neurotransmitters and cell membranes, lipid transport	Non-alcoholic fatty liver disease, muscle damage, interfered brain development in fetus	None	Liver damage, excessive sweating, hypotension	3500 mg/day

Summary of Fat-soluble Vitamins

Table 9.2.10: Fat-Soluble Vitamins

Vitamin	Sources	Recommended Intake for adults	Major functions	Deficiency diseases and symptoms	Groups at risk of deficiency	Toxicity	U
Vitamin A (retinol, retinal, retinoic acid,carotene, beta-carotene)	Retinol: beef and chicken liver, skim milk, whole milk, cheddar cheese; Carotenoids: pumpkin, carrots, squash, collards, peas	700-900 mcg/day	Antioxidant,vision, cell differentiation, reproduction, immune function	Xerophthalmia, night blindness, eye infections; poor growth, dry skin, impaired immune function	People living in poverty (especially infants and children), premature infants, pregnant and lactating women people who consume low-fat or low-protein diets	Hypervitaminosis A: Dry, itchy skin, hair loss, liver damage, joint pain, fractures, birth defects, swelling of the brain	3000 da
Vitamin D	Swordfish, salmon, tuna, orange juice (fortified), milk (fortified), sardines, egg, synthesis from sunlight	600-800 IU/day (15-20 mcg/day)	Absorption and regulation of calcium and phosphorus, maintenance of bone	Rickets in children: abnormal growth, misshapen bones, bowed legs, soft bones; osteomalacia in adults	Breastfed infants, older adults people with limited sun exposure, people with dark skin	Calcium deposits in soft tissues, damage to the heart, blood vessels, and kidneys	4000 (100 da
Vitamin E	Sunflower seeds, almonds, hazelnuts,peanuts	15 mg/day	Antioxidant, protects cell membranes	Broken red blood cells, nerve damage	People with poor fat absorption, premature infants	Inhibition of vitamin K clotting factors	1000 day f supple sou
Vitamin K	Vegetable oils, leafy greens, synthesis by intestinal bacteria	90-120 mcg/day	Synthesis of blood clotting proteins and proteins needed for bone health and cell growth	Hemorrhage	Newborns, people on long term antibiotics	Anemia, brain damage	N

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9.3: Vitamins and Energy Metabolism — B1, B2, Niacin, Pantothenic Acid, Biotin and Choline

All water-soluble vitamins play a different kind of role in energy metabolism; they are required as functional parts of enzymes involved in energy release and storage. Vitamins and minerals that make up part of enzymes are referred to as coenzymes and cofactors**,** respectively. Coenzymes and cofactors are required by enzymes to catalyze a specific reaction. They assist in converting a substrate to an end-product. Coenzymes and cofactors are essential in catabolic pathways and play a role in many anabolic pathways too. In addition to being essential for metabolism, many vitamins and minerals are required for blood renewal and function. At insufficient levels in the diet these vitamins and minerals impair the health of blood and consequently the delivery of nutrients in and wastes out, amongst its many other functions. In this section we will focus on the vitamins that take part in metabolism and blood function and renewal.

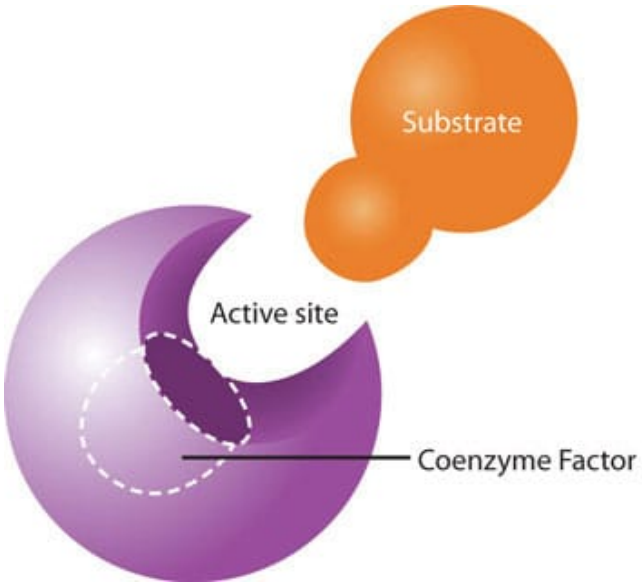


Figure 9.3.1: Enzyme Active Site for Cofactors. Coenzymes and cofactors are the particular vitamin or mineral required for enzymes to catalyze a specific reaction.

Vitamins Involved in Energy Metabolism

Have you ever heard that taking vitamins will give you more energy? Or have you bought a product that claimed it could boost your energy level because it has added vitamins? Based on the knowledge that you've learned in this course, you know that vitamins are not broken down in the body to provide energy. So where does the idea that vitamins give you energy come from? On this page we will provide an overview of the B vitamins and several minerals that are important to the process of energy metabolism in the body, and take a closer look at two of those vitamins (folate and vitamin B_{12}) that have some important implications in our health.

The Role of B Vitamins and Minerals in Energy Metabolism

All of the B vitamins and several minerals play a role in energy metabolism; they are required as functional parts of enzymes involved in energy release and storage. Many enzymes don't work optimally, or even at all, unless bound to other specific helper molecules, called ***coenzymes*** or ***cofactors***. Binding to these molecules promotes optimal conformation and function for their respective enzymes.

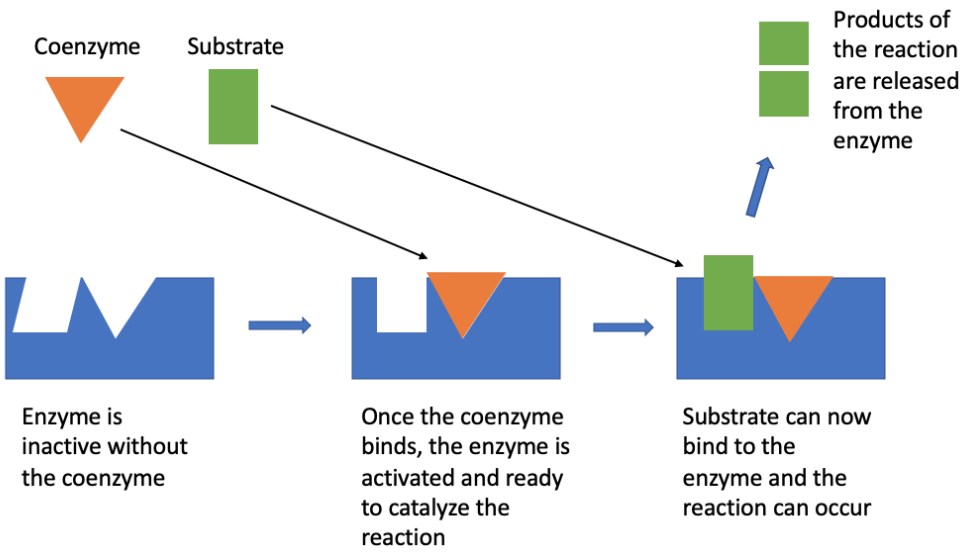


Figure 9.14. *Role of a coenzyme assisting in an enzymatic reaction to break down a substrate.*

Vitamins that bind to enzymes are referred to as **coenzymes—***organic* molecules which are required by enzymes to catalyze a specific reaction. They assist in converting a substrate to an end product. **Cofactors** are the *inorganic* minerals that assist in these enzymatic reactions. Coenzymes and cofactors are essential in ***catabolic pathways*** (i.e. breaking down substances) and play a role in many ***anabolic pathways*** (i.e. building substances). Table 9.1 lists the vitamins and minerals that participate in energy metabolism and their key functions in that process.

Nutrients Involved in Energy Metabolism	
B Vitamins	**Role in Energy Metabolism**
Thiamin (B_1)	Assists in glucose metabolism and RNA, DNA, and ATP synthesis
Riboflavin (B_2)	Assists in carbohydrate and fat metabolism
Niacin (B_3)	Assists in glucose, fat, and protein metabolism
Pantothenic Acid (B_5)	Assists in glucose, fat, and protein metabolism, cholesterol and neurotransmitter synthesis
Biotin (B_7)	Assists in amino acid synthesis and glucose, fat, and protein metabolism.
Choline	Assists in lipid transport and methyl group donation.

***Normally used instead of common names**

Table 9.1. Vitamins and minerals involved in energy metabolism and the role they each play.

Do B Vitamins Give You Energy?

Because B vitamins play so many important roles in energy metabolism, it is common to see marketing claims that B vitamins boost energy and performance. Some marketers claim taking a product with that contains one-thousand times the daily value of certain B vitamins boosts energy and performance. This is a myth that is not backed by science. The “feeling” of more energy from energy-boosting supplements stems more from the high amount of added sugars, caffeine, and other herbal stimulants that accompany the high doses of B vitamins in many these products. As discussed, B vitamins are needed to support energy metabolism and growth, but taking in more than required does not supply you with more energy. A great analogy of this phenomenon is the gas in your car. Does it drive faster with a half-tank of gas or a full one? It does not matter; the car drives just as fast as long as it has gas. Similarly, depletion of B vitamins will cause problems in energy metabolism, but having more than is required to run metabolism does not speed it up. And because B vitamins are water-soluble, they are not stored in the body and any excess will be excreted from the body, essentially flushing out the added expense of the supplements.

Deficiency and Excess

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; however in the nineteenth century some vitamin-B deficiencies plagued many people in North America. Niacin deficiency, also known as pellagra, was prominent in poorer Americans whose main dietary staple was refined cornmeal. Its symptoms were severe and included diarrhea, dermatitis, dementia, and even death. Some of the health consequences of pellagra are the result of niacin being in insufficient supply to support the body’s metabolic functions. However, when a deficiency of one of these vitamins does occur, symptoms can be seen throughout the body because of their relationship to energy metabolism, which happens in all cells of the body. A lack of these vitamins typically impairs blood health and the conversion of macronutrients into usable energy (i.e., ATP). Deficiency can also lead to an increase in susceptibility to infections, tiredness, lack of energy, and a decrease in concentration.[1] Groups most at risk for a deficiency in any of these micronutrients are people on calorie-limited diets, people with imbalanced or insufficient nutrition, people with eating disorders, and people experiencing extensive levels of physical or emotional stress.[1]

Because of their water-solubility, toxicities of most of these water-soluble vitamins are also uncommon, as excess intake is often excreted from the body. That doesn’t mean taking high doses comes without risks. Large quantities, particularly through supplements, can lead to adverse side effects or cause interactions with medications. For example, too much niacin can cause flushing of the skin or dangerous drops in blood pressure, and a high intake of B_6 can lead to neuropathy. When taking vitamin or mineral supplements, always pay attention to the recommended dietary allowance and avoid exceeding the tolerable upper intake level (UL).

Thiamin (B_1)

Thiamin is especially important in glucose metabolism. It acts as a cofactor for enzymes that break down glucose for energy production (Figure 9.7 “Enzyme Active Site for Cofactors”). Thiamin plays a key role in nerve cells as the glucose that is catabolized by thiamin is needed for an energy source. Additionally, thiamin plays a role in the synthesis of neurotransmitters and is therefore required for RNA, DNA, and ATP synthesis.

The brain and heart are most affected by a deficiency in thiamin. Thiamin deficiency, also known as beriberi, can cause symptoms of fatigue, confusion, movement impairment, pain in the lower extremities, swelling, and heart failure. It is prevalent in societies whose main dietary staple is white rice. During the processing of white rice, the bran is removed, along with what were called in the early nineteenth century, “accessory factors,” that are vital for metabolism. Dutch physician Dr. Christiaan Eijkman cured chickens of beriberi by feeding them unpolished rice bran in 1897. By 1912, Sir Frederick Gowland Hopkins determined from his experiments with animals that the “accessory factors,” eventually renamed vitamins, are needed in the diet to support growth, since animals fed a diet of pure carbohydrates, proteins, fats, and minerals failed to grow.[4]Eijkman and Hopkins were awarded the Nobel Prize in Physiology (or Medicine) in 1929 for their discoveries in the emerging science of nutrition.

Another common thiamin deficiency known as Wernicke- Korsakoff syndrome can cause similar symptoms as beriberi such as confusion, loss of coordination, vision changes, hallucinations, and may progress to coma and death. This condition is specific to alcoholics as diets high in alcohol can cause thiamin deficiency. Other individuals at risk include individuals who also consume diets typically low in micronutrients such as those with eating disorders, elderly, and individuals who have gone through gastric bypass surgery.[5]

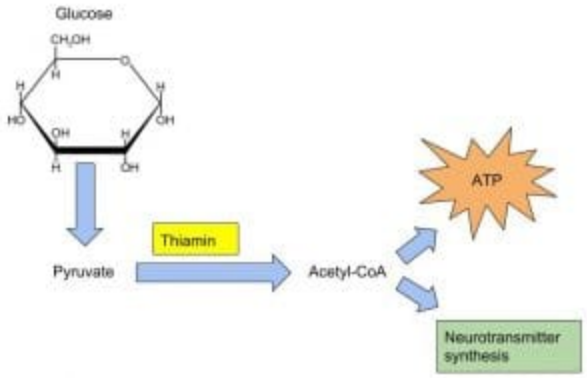


Figure 9.3.4: The Role of Thiamin. Image by Allison Calabrese / CC BY 4.0

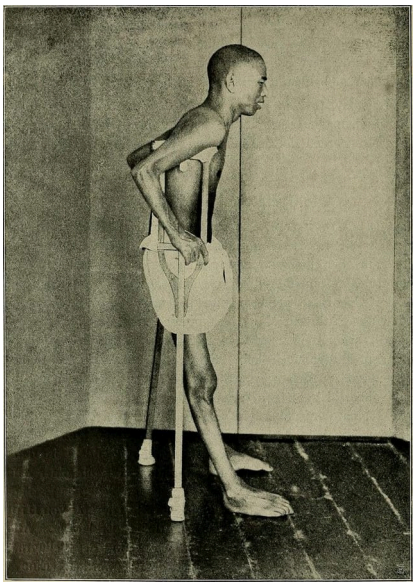


Figure 9.3.5: Beriberi, Thiamin Deficiency. Image by Casimir Funk (1914) / No known copyright restrictions

Dietary Reference Intakes

The RDAs and ULs for different age groups for thiamin are listed in Table 9.3.2. There is no UL for thiamin because there has not been any reports on toxicity when excess amounts are consumed from food or supplements.

Table 9.3.2: Dietary Reference Intakes for Thiamin

Age Group	RDA Males and Females mg/day
Infants (0–6 months)	0.2 *
Infants (7–12 months)	0.3
Children (1–3 years)	0.5
Children (4–8 years)	0.6
Children (9–13 years)	0.9
Adolescents (14–18 years)	1.2 (males), 1.0 (females)
Adults (> 19 years)	1.2 (males), 1.1 (females)
*denotes Adequate Intake	

Health Professional Fact Sheet: Thiamin. National Institutes of Health, Office of Dietary Supplements.https://ods.od.nih.gov/

factsheets/Thiamin-HealthProfessional/ . Updated February 11, 2016 . Accessed October 5, 2017.

Dietary Sources

Whole grains, meat and fish are great sources of thiamin. The United States as well as many other countries, fortify their refined breads and cereals. For the thiamin content of various foods, see Table 9.14.

Table 9.3.3: Thiamin Content of Various Foods

Food	Serving	Thiamin (mg)	Percent Daily Value
Breakfast cereals, fortified	1 serving	1.5	100
White rice, enriched	½ c.	1.4	73
Pork chop, broiled	3 oz.	0.4	27
Black beans, boiled	½ c.	0.4	27
Tuna, cooked	3 oz.	0.2	13
Brown rice, cooked, not enriched	½ c.	0.1	7
Whole wheat bread	1 slice	0.1	7
2% Milk	8 oz.	0.1	7
Cheddar cheese	1 ½ oz	0	0
Apple, sliced	1 c.	0	0

Health Professional Fact Sheet: Thiamin. National Institutes of Health, Office of Dietary Supplements.https://ods.od.nih.gov/factsheets/Thiamin-HealthProfessional/ . Updated February 11, 2016 . Accessed October 5, 2017.

Riboflavin (B2)

Riboflavin is an essential component of flavoproteins, which are coenzymes involved in many metabolic pathways of carbohydrate, lipid, and protein metabolism. Flavoproteins aid in the transfer of electrons in the electron transport chain. Furthermore, the functions of other B-vitamin coenzymes, such as vitamin B_6 and folate, are dependent on the actions of flavoproteins. The “flavin” portion of riboflavin gives a bright yellow color to riboflavin, an attribute that helped lead to its discovery as a vitamin. When riboflavin is taken in excess amounts (supplement form) the excess will be excreted through your kidneys and show up in your urine. Although the color may alarm you, it is harmless. There are no adverse effects of high doses of riboflavin from foods or supplements that have been reported.

Riboflavin deficiency, sometimes referred to as ariboflavinosis, is often accompanied by other dietary deficiencies (most notably protein) and can be common in people that suffer from alcoholism. This deficiency will usually also occur in conjunction with deficiencies of other B vitamins because the majority of B vitamins have similar food sources. Its signs and symptoms include dry, scaly skin, cracking of the lips and at the corners of the mouth, sore throat, itchy eyes, and light sensitivity.

Dietary Reference Intakes

The RDAs for different age groups for riboflavin are listed in Table 9.3.4. There is no UL for riboflavin because no toxicity has been reported when an excess amount has been consumed through foods or supplements.

Table 9.3.4: Dietary Reference Intakes for Riboflavin

Age Group	RDA Males and Females mg/day
Infants (0–6 months)	0.3 *
Infants (7–12 months)	0.4*
Children (1–3 years)	0.5

Age Group	RDA Males and Females mg/day
Children (4–8 years)	0.6
Children (9–13 years)	0.9
Adolescents (14–18 years)	1.3 (males), 1.0 (females)
Adults (> 19 years)	1.3 (males), 1.1 (females)
*denotes Adequate Intake	

Fact Sheet for Health Professionals, Riboflavin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Riboflavin-HealthProfessional/. Updated February 11, 2016. Accessed October 22, 2017.

Dietary Sources

Riboflavin can be found in a variety of different foods but it is important to remember that it can be destroyed by sunlight. Milk is one of the best sources of riboflavin in the diet and was once delivered and packaged in glass bottles. This packaging has changed to cloudy plastic containers or cardboard to help block the light from destroying the riboflavin in milk. For the riboflavin content of various foods, see Table 9.3.1.

Table 9.3.5: Riboflavin Content of Various Foods

Food	Serving	Riboflavin (mg)	Percent Daily Value
Beef liver	3 oz.	2.9	171
Breakfast cereals, fortified	1 serving	1.7	100
Instant oats, fortified	1 c.	1.1	65
Plain yogurt, fat free	1 c.	0.6	35
2% milk	8 oz.	0.5	29
Beef, tenderloin steak	3 oz.	0.4	24
Portabella mushrooms, sliced	½ c.	0.3	18
Almonds, dry roasted	1 oz.	0.3	18
Egg, scrambled	1 large	0.2	12
Quinoa	1 c.	0.2	12
Salmon, canned	3 oz.	0.2	12
Spinach, raw	1 c.	0.1	6
Brown rice	½ c.	0	0

Fact Sheet for Health Professionals, Riboflavin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Riboflavin-HealthProfessional/. Updated February 11, 2016. Accessed October 22, 2017.

Niacin (B_3)

Niacin is a component of the coenzymes NADH and NADPH, which are involved in the catabolism and/or anabolism of carbohydrates, lipids, and proteins. NADH is the predominant electron carrier and transfers electrons to the electron-transport chain to make ATP. NADPH is also required for the anabolic pathways of fatty-acid and cholesterol synthesis. In contrast to other vitamins, niacin can be synthesized by humans from the amino acid tryptophan in an anabolic process requiring enzymes dependent on riboflavin, vitamin B_6, and iron. Niacin is made from tryptophan only after tryptophan has met all of its other needs in the body. The contribution of tryptophan-derived niacin to niacin needs in the body varies widely and a few scientific studies have demonstrated that diets high in tryptophan have very little effect on niacin deficiency.

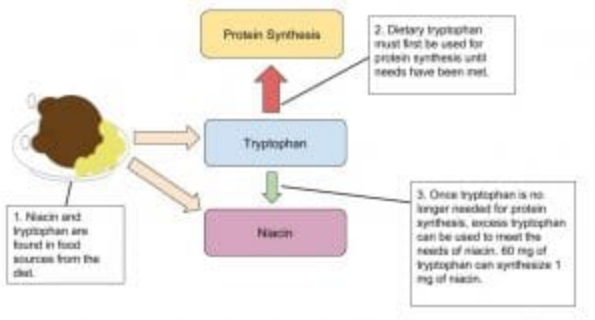


Figure 9.3.6: Conversion of Tryptophan to Niacin. Image by Allison Calabrese / CC BY 4.0



Figure 9.3.7: Niacin Deficiency, Pellagra. Image by Herbert L. Fred, MD, Hendrik A. van Dijk / CC BY-SA 3.0

A deficiency in niacin causes a disease called pellagra, which was common in the early twentieth century in some parts of the United States. The common signs and symptoms of pellagra are known as the "4D's—diarrhea, dermatitis, dementia, and death." Until scientists discovered that better diets relieved the signs and symptoms of pellagra, many people with the disease ended up hospitalized and in asylums awaiting death. The following video gives an overview of pellagra and how its cure was discovered through a change in diet.

YouTube Video

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

View this YouTube Video online

VIDEO: "Pellagra video" by Teresa Johnson, YouTube (June 20, 2012), 5:49 minutes.

By contrast, Indigenous peoples of the Americas whose diets included corn did not experience pellagra. This stark contrast was not due to genetic differences or environmental factors, but rather to a critical difference in food processing. Indigenous cultures throughout Mesoamerica had long practiced nixtamalization, a technique that involves soaking and cooking corn in an alkaline solution — traditionally made with wood ash or lime (calcium hydroxide). This process does more than soften the kernels and improve flavor and texture — it chemically transforms the corn by releasing niacin from its bound form, making it bioavailable to the human body.

Though corn is naturally rich in niacin, without nixtamalization, most of it remains locked in a form our digestive systems cannot absorb. European settlers in the Americas, unfamiliar with this traditional processing method, consumed cornmeal and grits made from untreated corn, and as a result, suffered from widespread pellagra when corn became a staple food. In contrast, Indigenous communities that nixtamalized their corn avoided the disease entirely, despite relying heavily on corn as a dietary foundation. This powerful example illustrates how traditional food knowledge and processing methods can dramatically influence nutritional outcomes — highlighting that it's not just what we eat, but how we prepare it, that determines whether food meets our physiological needs. For more on nixtamalization, see this article on transforming corn (2016).





Dietary Reference Intakes

The RDAs and ULs for different age groups for Niacin are listed in Table 9.17. Because Niacin needs can be met from tryptophan, The RDA is expressed in niacin equivalents (NEs). The conversions of NE, Niacin, and tryptophan are: 1 mg NE= 60 mg tryptophan= 1 mg niacin

Table 9.3.6: Dietary Reference Intakes for Niacin

Age Group	RDA Males and Females mg NE/day)	UL
Infants (0–6 months)	2 *	Not possible to establish
Infants (7–12 months)	4*	Not possible to establish
Children (1–3 years)	6	10
Children (4–8 years)	8	15
Children (9–13 years)	12	20
Adolescents (14–18 years)	16 (males), 14 (females)	30
Adults (> 19 years)	16 (males), 14 (females)	35
*denotes Adequate Intake		

Micronutrient Information Center: Niacin. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/niacin. Updated in July 2013. Accessed October 22, 2017.

Dietary Sources

Niacin can be found in a variety of different foods such as yeast, meat, poultry, red fish, and cereal. In plants, especially mature grains, niacin can be bound to sugar molecules which can significantly decrease the niacin bioavailability. For the niacin content of various foods, see Table 9.3.7.

Table 9.3.7: Niacin Content of Various Foods

Food	Serving	Niacin (mg)	Percent Daily Value
Chicken	3 oz.	7.3	36.5
Tuna	3 oz.	8.6	43
Turkey	3 oz.	10.0	50
Salmon	3 oz.	8.5	42.5
Beef (90% lean)	3 oz.	4.4	22
Cereal (unfortified)	1 c.	5	25
Cereal (fortified)	1 c.	20	100
Peanuts	1 oz.	3.8	19
Whole wheat bread	1 slice	1.3	6.5
Coffee	8 oz.	0.5	2.5

Micronutrient Information Center: Niacin. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/niacin. Updated in July 2013. Accessed October 22, 2017.

Pantothenic Acid (B5)

Figure 9.3.8: Pantothenic Acid's Role in the Citric Acid Cycle. Pantothenic Acid (Vitamin B5) makes up coenzyme A, which carries the carbons of glucose, fatty acids, and amino acids into the citric acid cycle as Acetyl-CoA. Adaptation by ChatGPT (2025)

Pantothenic acid forms coenzyme A, which is the main carrier of carbon molecules in a cell. Acetyl-CoA is the carbon carrier of glucose, fatty acids, and amino acids into the citric acid cycle (Figure 9.14 "Pantothenic Acid's Role in the Citric Acid Cycle"). Coenzyme A is also involved in the synthesis of lipids, cholesterol, and acetylcholine (a neurotransmitter). A Pantothenic Acid deficiency is exceptionally rare. Signs and symptoms include fatigue, irritability, numbness, muscle pain, and cramps. You may have seen pantothenic acid on many ingredients lists for skin and hair care products; however there is no good scientific evidence that pantothenic acid improves human skin or hair.

Dietary Reference Intakes

Because there is little information on the requirements for pantothenic acids, the Food and Nutrition Board (FNB) has developed Adequate Intakes (AI) based on the observed dietary intakes in healthy population groups. The AI for different age groups for pantothenic acid are listed in Table 9.3.1.

Table 9.3.8: Dietary Reference Intakes for Pantothenic Acid

Age Group	AI Males and Females mg/day)
Infants (0–6 months)	1.7
Infants (7–12 months)	1.8
Children (1–3 years)	2
Children (4–8 years)	3
Children (9–13 years)	4
Adolescents (14–18 years)	5
Adults (> 19 years)	5

Micronutrient Information Center: Pantothenic Acid. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/patothenic-acid . Updated in July 2013. Accessed October 22, 2017.

Dietary Sources

Pantothenic Acid is widely distributed in all types of food, which is why a deficiency in this nutrient is rare. Pantothenic Acid gets its name from the greek word “pantothen” which means “from everywhere”. For the pantothenic acid content of various foods, see Table 9.20 Pantothenic Acid Content of Various Foods”.

Table 9.3.8: Pantothenic Acid Content of Various Foods

Food	Serving	Pantothenic Acid (mg)	Percent Daily Value
Sunflower seeds	1 oz.	2	20
Fish, trout	3 oz.	1.9	19
Yogurt, plain nonfat	8 oz.	1.6	16
Lobster	3 oz.	1.4	14
Avocado	½ fruit	1	10
Sweet potato	1 medium	1	10
Milk	8 fl oz.	0.87	8.7
Egg	1 large	0.7	7
Orange	1 whole	0.3	3
Whole wheat bread	1 slice	0. 21	2.1

Micronutrient Information Center: Pantothenic Acid. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/vitamins/patothenic-acid . Updated in July 2013. Accessed October 22, 2017.

Biotin

Biotin is required as a coenzyme in the citric acid cycle and in lipid metabolism. It is also required as an enzyme in the synthesis of glucose and some nonessential amino acids. A specific enzyme, biotinidase, is required to release biotin from protein so that it can be absorbed in the gut. There is some bacterial synthesis of biotin that occurs in the colon; however this is not a significant

source of biotin. Biotin deficiency is rare, but can be caused by eating large amounts of raw egg whites over an extended period of time. This is because a protein in raw egg whites — avidin — tightly binds to biotin, making it unavailable for absorption. Cooking egg whites denatures the protein avidin, preventing it from binding biotin and eliminating this concern. As a result, biotin remains bioavailable when eggs are cooked.

A rare genetic disease-causing malfunction of the biotinidase enzyme also results in biotin deficiency. Symptoms of biotin deficiency are similar to those of other B vitamins, but may also include hair loss when severe.

Dietary Reference Intakes

Because there is little information on the requirements for biotin, the FNB has developed Adequate Intakes (AI) based on the observed dietary intakes in healthy population groups. The AI for different age groups for biotin are listed in Table 9.3.1.

Table 9.3.9: Dietary Reference Intakes for Biotin

Age Group	AI Males and Females mcg/day)
Infants (0–6 months)	5
Infants (7–12 months)	6
Children (1–3 years)	8
Children (4–8 years)	12
Children (9–13 years)	20
Adolescents (14–18 years)	25
Adults (> 19 years)	30

Fact Sheet for Health Professionals: Biotin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Biotin-HealthProfessional/. Updated October 3, 2017. Accessed November 10, 2017.

Dietary Sources

Biotin can be found in foods such as eggs, fish, meat, seeds, nuts and certain vegetables. For the pantothenic acid content of various foods, see Table 9.3.10.

Table 9.3.10: Biotin Content of Various Foods

Food	Serving	Biotin (mcg)	Percent Daily Value*
Eggs	1 large	10	33.3
Salmon, canned	3 oz.	5	16.6
Pork chop	3 oz.	3.8	12.6
Sunflower seeds	¼ c.	2.6	8.6
Sweet potato	½ c.	2.4	8
Almonds	¼ c.	1.5	5
Tuna, canned	3 oz.	0.6	2
Broccoli	½ c.	0.4	1.3
Banana	½ c.	0.2	0.6
* Current AI used to determine Percent Daily Value			

Fact Sheet for Health Professionals: Biotin. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Biotin-HealthProfessional/. Updated October 3, 2017. Accessed November 10, 2017.

Choline

Choline is a water-soluble substance that is not classified as a vitamin because it can be synthesized by the body. However, the synthesis of choline is limited and therefore it is recognized as an essential nutrient. Choline is need to perform functions such as the synthesis of neurotransmitter acetylcholine, the synthesis of phospholipids used to make cell membranes, lipid transport, and also homocysteine metabolism. A deficiency in choline may lead to interfered brain development in the fetus during pregnancy, and in adults cause fatty liver and muscle damage.

Dietary Reference Intakes

There is insufficient data on choline so the FNB has developed AIs for all ages in order to prevent fatty liver disease. The AI and UL for different age groups for choline are listed in Table 9.3.17.

Table 9.3.17: Dietary Reference Intakes for Choline

Age Group	AI Males and Females mg/day)	UL
Infants (0–6 months)	125	–
Infants (7–12 months)	150	–
Children (1–3 years)	200	1000
Children (4–8 years)	250	1000
Children (9–13 years)	375	2000
Adolescents (14–18 years)	550 (males), 400 (females)	3000
Adults (> 19 years)	550 (males), 425 (females)	3500

Fact Sheet for Health Professionals: Choline. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Choline-HealthProfessional/. Updated January 25, 2017. Accessed October 28, 2017.

Dietary Sources

Choline can be found in a variety of different foods. The main dietary sources of choline in the United States are animal-source foods. When concerns about dietary cholesterol led many Americans to avoid eggs, intake of choline — which is abundant in egg yolks — declined, increasing the risk of choline inadequacy. For the Choline content of various foods, see Table 9.3.18.

Table 9.3.18: Choline Content of Various Foods

Food	Serving	Choline (mg)	Percent Daily Value
Egg	1 large	147	27
Soybeans	½ cup	107	19
Chicken breast	3 oz.	72	13
Mushrooms, shiitake	½ c.	58	11
Potatoes	1 large	57	10
Kidney beans	½ c.	45	8
Peanuts	¼ c.	24	4
Brown rice	1 c.	19	3

Fact Sheet for Health Professionals: Choline. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Choline-HealthProfessional/. Updated January 25, 2017. Accessed October 28, 2017.

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9.4: Vitamins and Healthy Blood — B6, Folate, B12, K

Blood is essential to life. It transports absorbed nutrients and oxygen to cells, removes metabolic waste products for excretion, and carries molecules, such as hormones, to allow for communication between organs.

Blood is a connective tissue of the circulatory system, made up of four components forming a matrix:

- **red blood cells** (or erythrocytes), which transport oxygen to cells
- **white blood cells** (or leukocytes), which are part of the immune system and help destroy foreign invaders
- **platelets,** which are fragments of cells that circulate to assist in blood clotting
- **plasma,** which is the fluid portion of the blood and contains proteins that help transport nutrients (e.g., fat-soluble vitamins) and aid in blood clotting.

Maintaining healthy blood, including its continuous renewal, is essential to support its vital functions. Blood health is acutely sensitive to deficiencies in some vitamins and minerals, especially vitamin B6, folate, vitamin B12 (cobalamine), and vitamin K.

Vitamin B_6 (Pyridoxine)

Vitamin B_6 is the coenzyme involved in a wide variety of functions in the body. One major function is the nitrogen transfer between amino acids which plays a role in amino-acid synthesis and catabolism. Also, it functions to release glucose from glycogen in the catabolic pathway of glycogenolysis and is required by enzymes for the synthesis of multiple neurotransmitters and hemoglobin (Figure 9.4.9).

Vitamin B_6 is also a required coenzyme for the synthesis of hemoglobin. A deficiency in vitamin B_6 can cause anemia, but it is of a different type than that caused by insufficient folate, cobalamin, or iron; although the symptoms are similar. The size of red blood cells is normal or somewhat smaller but the hemoglobin content is lower. This means each red blood cell has less capacity for carrying oxygen, resulting in muscle weakness, fatigue, and shortness of breath. Other deficiency symptoms of vitamin B_6 can cause dermatitis, mouth sores, and confusion.

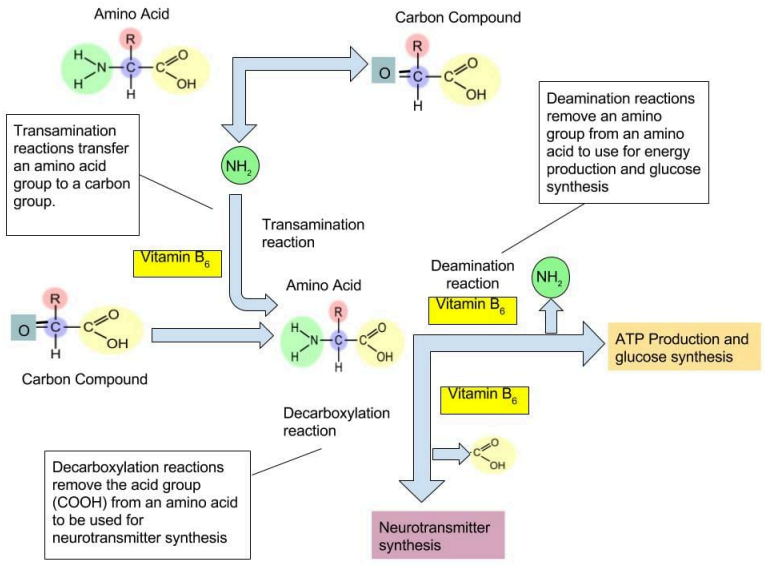


Figure 9.4.9: The Function of Vitamin B6 in Amino Acid Metabolism. Image by Allison Calabrese / CC BY 4.0

The vitamin B_6 coenzyme is needed for a number of different reactions that are essential for amino acid synthesis, catabolism for energy, and the synthesis of glucose and neurotransmitters.

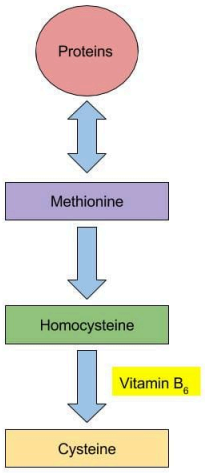


Figure 9.4.10: Vitamin B_6 Functional Coenzyme Role. Image by Allison Calabrese / CC BY 4.0

Vitamin B6 coenzyme is essential for the conversion of amino acid methionine into cysteine. With low levels of Vitamin B6, homocysteine will build up in the blood. High levels of homocysteine increases the risk for heart disease.

Vitamin B_6 Toxicity

Currently, there are no adverse effects that have been associated with a high dietary intake of vitamin B6, but large supplemental doses can cause severe nerve impairment. To prevent this from occurring, the UL for adults is set at 100 mg/day.

Dietary Reference Intakes

The RDAs and ULs for different age groups for vitamin B_6 are listed in Table 9.4.11.

Table 9.4.11: Dietary Reference Intakes for Vitamin B_6

Age Group	RDA Males and Females mg/day	UL
Infants (0–6 months)	0.1*	Not possible to determine
Infants (7–12 months)	0.3*	Not possible to determine
Children (1–3 years)	0.5	30
Children (4–8 years)	0.6	40
Children (9–13 years)	1	60
Adolescents (14–18 years)	1.3 (males), 1.2 (females)	80
Adults (> 19 years)	1.3	100
*denotes Adequate Intake		

Dietary Supplement Fact Sheet: Vitamin B_6. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB6-HealthProfessional/. Updates February 11, 2016. Accessed October 22, 2017.

Dietary Sources

Vitamin B_6 can be found in a variety of foods. The richest sources include fish, beef liver and other organ meats, potatoes, and other starchy vegetables and fruits. For the Vitamin B_6 content of various foods, see Table 9.24 Vitamin B_6 Content of Various

Foods".

Table 9.4.12: Vitamin B_6 Content of Various Foods

Food	Serving	Vitamin B6 (mg)	Percent Daily Value
Chickpeas	1 c.	1.1	55
Tuna, fresh	3 oz.	0.9	45
Salmon	3 oz.	0.6	30
Potatoes	1 c.	0.4	20
Banana	1 medium	0.4	20
Ground beef patty	3 oz.	0.3	10
White rice, enriched	1 c.	0.1	5
Spinach	½ c	0.1	5

Dietary Supplement Fact Sheet: Vitamin B_6. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB6-HealthProfessional/. Updates February 11, 2016. Accessed October 22, 2017.

Folate

Folate, or vitamin B_9, is a required coenzyme for the synthesis of several amino acids and for making RNA and DNA. Therefore, rapidly dividing cells are most affected by folate deficiency. Red blood cells, white blood cells, and platelets are continuously being synthesized in the bone marrow from dividing stem cells. When folate is deficient, cells cannot divide normally. A consequence of folate deficiency is ***macrocytic anemia***. Macrocytic means "big cell," and anemia refers to fewer red blood cells or red blood cells containing less hemoglobin. Macrocytic anemia is characterized by larger and fewer red blood cells that are less efficient at carrying oxygen to cells. It is caused by red blood cells being unable to produce DNA and RNA fast enough—cells grow but do not divide, making them large in size.

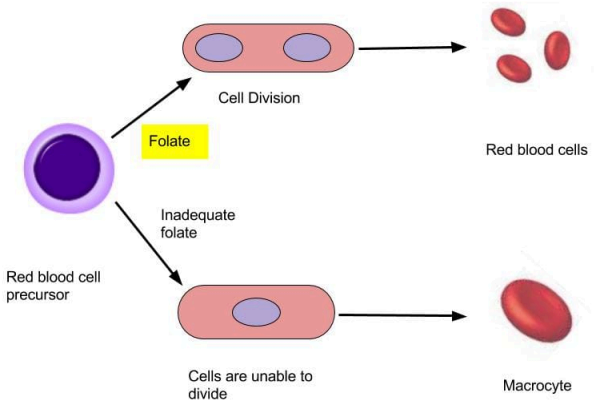


Figure 9.15. Folate and the formation of macrocytic anemia.

Folate is especially essential for the growth and specialization of cells of the central nervous system. Children whose mothers were folate-deficient during pregnancy have a higher risk of neural tube birth defects. Folate deficiency is causally linked to the development of ***spina bifida,*** a neural tube defect that occurs in a developing fetus when the spine does not completely enclose the spinal cord. Spina bifida can lead to many physical and mental disabilities (Figure 9.16). In 1998, the U.S. Food and Drug Administration (FDA) began requiring manufacturers to fortify enriched breads, cereals, flours, and cornmeal with ***folic acid*** (a

synthetic form of folate) to increase the consumption of folate in the American diet and reduce the risk of neural tube defects. Observational studies show that the prevalence of neural tube defects was decreased after the fortification of enriched cereal and grain products with folate compared to before these products were fortified.

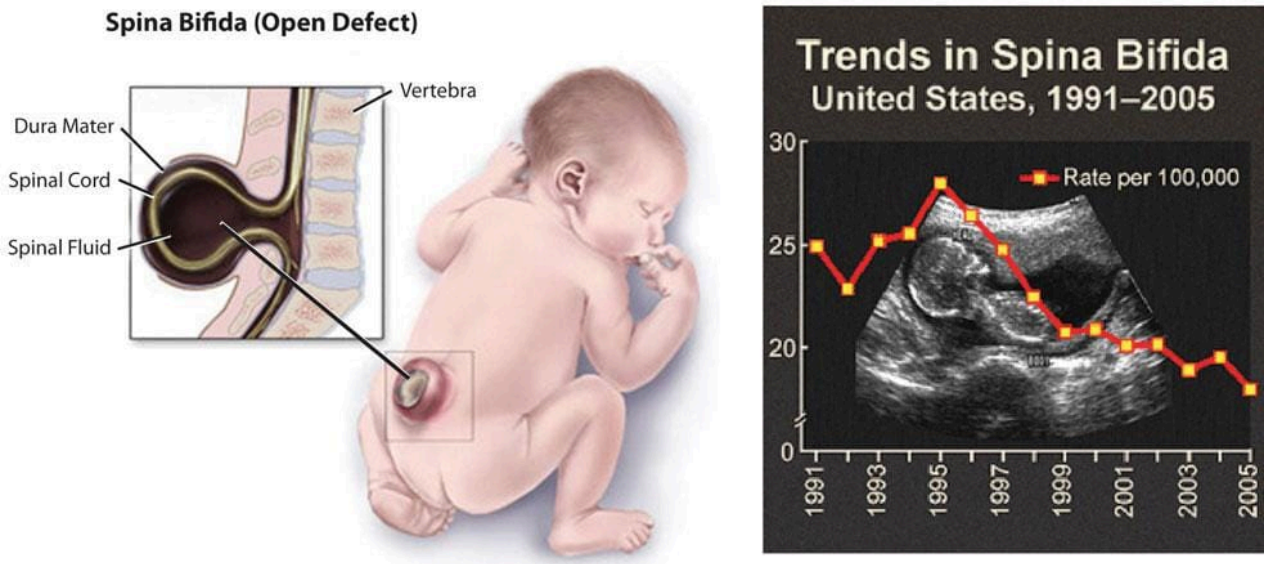


Figure 9.16. Spina bifida (left) is a neural tube defect that can have serious health consequences. The prevalence of cases of spina bifida has decreased significantly with the fortification of cereal and grain products in the United States beginning in 1998.

Additionally, results of clinical trials have demonstrated that neural tube defects are significantly decreased in the offspring of mothers who began taking folic acid supplements one month prior to becoming pregnant and throughout pregnancy. In response to the scientific evidence, the Food and Nutrition Board of the Institute of Medicine (IOM) raised the RDA for folate to 600 micrograms per day for pregnant women.

Dietary Sources of Folate

Folate is found naturally in a wide variety of foods, including vegetables (particularly dark leafy greens), fruits, nuts, beans, legumes, meat, poultry, eggs, and grains. As mentioned previously, folic acid (the synthetic form of folate) is also found in enriched foods such as grains.

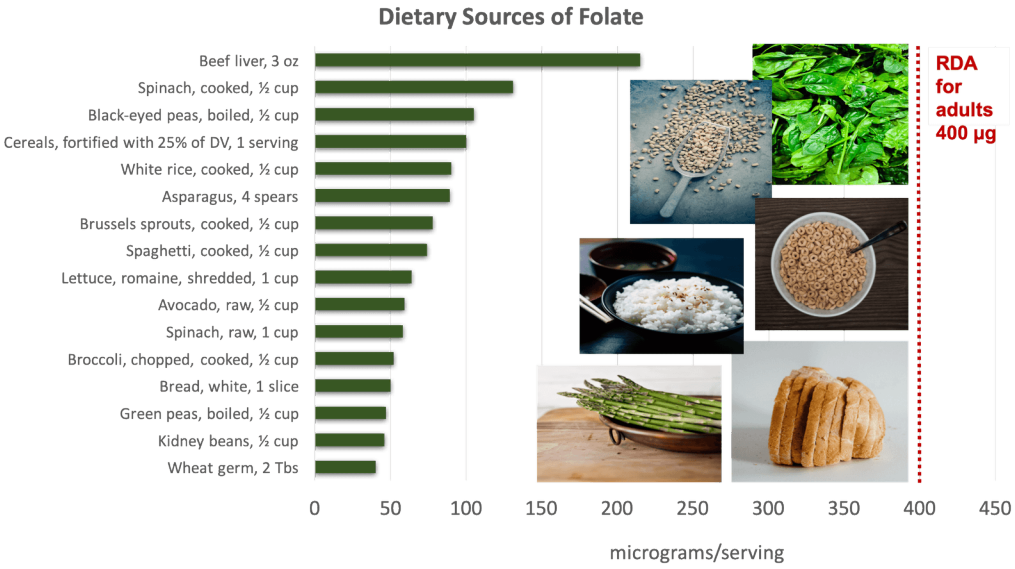


Figure 9.17. Dietary sources of folate. Examples of good sources pictured include spinach, black-eyed peas, fortified cereal, rice,

and bread and asparagus. Source: NIH *Office of Dietary Supplements*

Dietary Reference Intakes

The RDAs and ULs for different age groups for folate are listed in Table 9.25 "Dietary Reference Intakes for Folate ". Folate is a compound that is found naturally in foods. Folic acid however is the chemical structure form that is used in dietary supplements as well as enriched foods such as grains. The FNB has developed dietary folate equivalents (DFE) to reflect the fact that folic acid is more bioavailable and easily absorbed than folate found in food. The conversions for the different forms are listed below.

- 1 mcg DFE = 1 mcg food folate
- 1 mcg DFE = 0.6 mcg folic acid from fortified foods or dietary supplements consumed with foods
- 1 mcg DFE = 0.5 mcg folic acid from dietary supplements taken on an empty stomach

Table 9.4.13: Dietary Reference Intakes for Folate

Age Group	RDA Males and Females mcg DFE/day	UL
Infants (0–6 months)	65*	Not possible to determine
Infants (7–12 months)	80*	Not possible to determine
Children (1–3 years)	150	300
Children (4–8 years)	200	400
Children (9–13 years)	300	600
Adolescents (14–18 years)	400	800
Adults (> 19 years)	400	1000
*denotes Adequate Intake		

Dietary Supplement Fact Sheet: Folate. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Folate-HealthProfessional/. Updated April 20, 2016. Accessed October 22, 2017.

Dietary Sources

Folate is found naturally in a wide variety of food especially in dark leafy vegetables, fruits, and animal products. The U.S. Food and Drug Administration (FDA) began requiring manufacturers to fortify enriched breads, cereals, flours, and cornmeal to increase the consumption of folate in the American diet. For the folate content of various foods, see Table 9.26.

Table 9.4.14: Folate Content of Various Foods

Food	Serving	Folate (mcg DFE)	Percent Daily Value
Beef Liver	3 oz.	215	54
Fortified breakfast cereals	¾ c.	400	100
Spinach	½ c.	131	33
White rice, enriched	½ c.	90	23
Asparagus	4 spears	85	20
White bread, enriched	1 slice	43	11
Broccoli	2 spears	45	10
Avocado	½ c.	59	15
Orange juice	6 oz.	35	9
Egg	1 large	22	6

Dietary Supplement Fact Sheet: Folate. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Folate-HealthProfessional/. Updated April 20, 2016. Accessed October 22, 2017.

Folate Deficiency and Excess

Folate deficiency is typically due to an inadequate dietary intake; however, smoking and heavy, chronic alcohol intake can also decrease absorption, leading to a folate deficiency.[2] The primary sign of a folate deficiency is macrocytic anemia, characterized by large, abnormal red blood cells, which can lead to symptoms of fatigue, weakness, poor concentration, headache, irritability, and shortness of breath. Other symptoms of folate deficiency can include mouth sores, gastrointestinal distress, and changes in the skin, hair and nails. Women with insufficient folate intakes are at increased risk of giving birth to infants with neural tube defects and low intake during pregnancy has been associated with preterm delivery, low birth weight, and fetal growth retardation.[3]

Toxicity of folate is not typically seen due to an excess consumption from foods. However, there is concern regarding a high intake of folic acid from supplements because it could mask a deficiency in vitamin B_{12}. Because folate and vitamin B_{12} deficiencies are manifested by similar anemias, if a person with vitamin B_{12} deficiency is taking a high dose of folic acid, the macrocytic anemia would be corrected while the underlying B_{12} deficiency went undetected, which could result in significant neurological damage. Thus, a tolerable upper intake level (UL) has been established for folate to prevent irreversible neurological damage due to high folic acid intake masking a B_{12} deficiency.[2]

Vitamin B12 (Cobalamin)

Vitamin B_{12} is a unique vitamin because it contains an element (cobalt) and is found almost exclusively in animal products. Neither plants nor animals can synthesize vitamin B_{12}; only bacteria can synthesize it. The vitamin B_{12} found in animal-derived foods was produced by microorganisms within the animals. Animals consume the microorganisms in soil, or microorganisms in the GI tract of animals produce vitamin B_{12} that can then be absorbed.

Vitamin B_{12} helps to prevent the breakdown of the ***myelin sheath,*** a cover that surrounds and protects nerve cells. It is also an essential part of coenzymes. It is necessary for fat and protein catabolism, folate coenzyme function, and hemoglobin synthesis. 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 a folate deficiency. In children and adults, vitamin B_{12} deficiency causes macrocytic anemia, and in babies born to cobalamin-deficient mothers there is an increased risk for neural tube defects.

In order for the human body to absorb vitamin B_{12}, the stomach, pancreas, and small intestine must be functioning properly. Cells in the stomach secrete a protein called ***intrinsic factor*** that is necessary for vitamin B_{12} absorption, which occurs in the small intestine. Impairment of secretion of this protein either caused by an autoimmune disease or by chronic inflammation of the stomach (such as that occurring in some people with H.pylori infection), can lead to the disease ***pernicious anemia***, a type of macrocytic anemia. Vitamin B_{12} malabsorption is most common in older adults, who may have impaired functioning of digestive organs, a normal consequence of aging.

Vitamin B_{12} and folate play key roles in converting ***homocysteine***, an amino acid found in the blood, to the amino acid methionine. High levels of homocysteine in the blood increases the risk for heart disease. Low levels of vitamin B_{12}, folate, or vitamin B_6 will increase homocysteine levels, thereby increasing the risk of heart disease.

Dietary Sources of Vitamin B12

Vitamin B_{12} is found naturally in animal products such as fish, meat, poultry, eggs, and milk products. Although vitamin B_{12} is not generally present in plant foods, fortified breakfast cereals are also a good source of vitamin B_{12}. Because vitamin B_{12} is only found primarily in animal products, it is important for strict vegetarians who consume no animal products (***vegans***) to get vitamin B_{12} either through supplements, nutritional yeast, or fortified products like cereals and soy milk. Recent research suggests some plant-based sources like edible algae, mushrooms, and fermented vegetables may contain substantial amounts of vitamin B_{12} as well.[2]

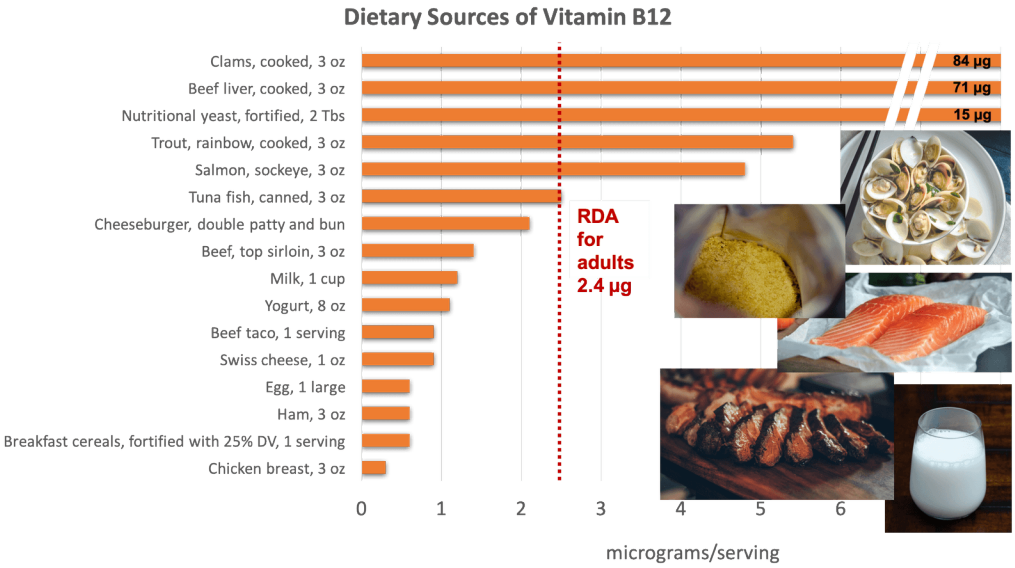


Figure 9.18. Dietary sources of vitamin B $_{12}$. *Examples of good sources pictured include clams, salmon, nutritional yeast, red meat, and milk. Source: NIH Office of Dietary Supplements , www.bragg.com*

Vitamin B12 (Cobalamin)

Vitamin B_{12} contains cobalt, making it the only vitamin that contains a metal ion. Vitamin B_{12} is an essential part of coenzymes. It is necessary for fat and protein catabolism, for folate coenzyme function, and for hemoglobin synthesis. An enzyme requiring vitamin B_{12} is needed by a folate-dependent enzyme to synthesize DNA. Thus, a deficiency in vitamin B_{12} has similar consequences to health as folate deficiency. In children and adults vitamin B_{12} deficiency causes macrocytic anemia, and in babies born to cobalamin-deficient mothers there is an increased risk for neural-tube defects. In order for the human body to absorb vitamin B_{12}, the stomach, pancreas, and small intestine must be functioning properly. Cells in the stomach secrete a protein called intrinsic factor that is necessary for vitamin B_{12} absorption, which occurs in the small intestine. Impairment of secretion of this protein either caused by an autoimmune disease or by chronic inflammation of the stomach (such as that occurring in some people with H.pylori infection), can lead to the disease pernicious anemia, a type of macrocytic anemia. Vitamin B_{12} malabsorption is most common in the elderly, who may have impaired functioning of digestive organs, a normal consequence of aging. Pernicious anemia is treated by large oral doses of vitamin B_{12} or by putting the vitamin under the tongue, where it is absorbed into the bloodstream without passing through the intestine. In patients that do not respond to oral or sublingual treatment vitamin B_{12} is given by injection.

Vitamin B_{12} Relationship with Folate and Vitamin B_6

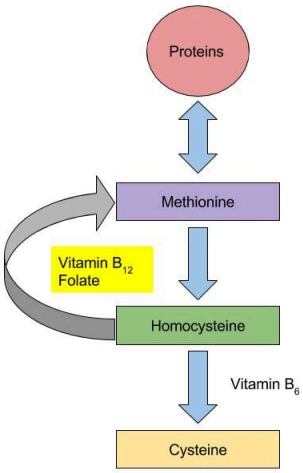


Figure 9.4.13: B Vitamins Coenzyme Roles. Image by Allison Calabrese / CC BY 4.0

Vitamin B_{12} and folate play key roles in converting homocysteine to amino acid methionine. As mentioned in Figure 9.19, high levels of homocysteine in the blood increases the risk for heart disease. Low levels of vitamin B_{12}, folate or vitamin B6 will increase homocysteine levels therefore increasing the risk of heart disease.

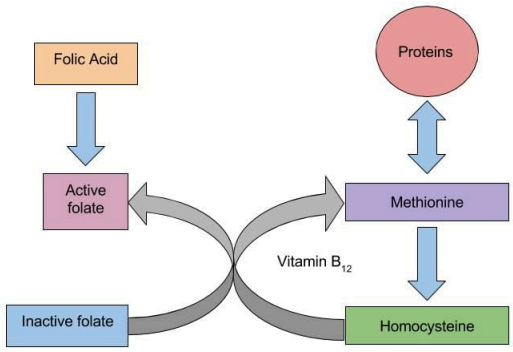


Figure 9.4.14: The Relationship Between Folate and Vitamin B_{12}. Image by Allison Calabrese / CC BY 4.0

When there is a deficiency in vitamin B_{12} , inactive folate (from food) is unable to be converted to active folate and used in the body for the synthesis of DNA. Folic Acid however (that comes from supplements or fortified foods) is available to be used as active folate in the body without vitamin B_{12} .Therefore, if there is a deficiency in vitamin B_{12} macrocytic anemia may occur. With the fortification of foods incorporated into people's diets, the risk of an individual developing macrocytic anemia is decreased.

Dietary Reference Intakes

The RDAs and ULs for different age groups for Vitamin B_{12} are listed in Table 9.4.15.

Table 9.4.15: Dietary Reference Intakes for Vitamin B_{12}

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

Dietary Fact Sheet: Vitamin B12. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB12-HealthProfessional/. Updated February 11, 2016. Accessed October 28, 2017.

Dietary Sources

Vitamin B_{12} is found naturally in animal products such as fish, meat, poultry, eggs, and milk products. Although vitamin B_{12} is not generally present in plant foods, fortified breakfast cereals are also a good source of vitamin B_{12}. For the vitamin B_{12} content of various foods, see Table 9.4.16.

Table 9.4.16: Vitamin B_{12} Content of Various Foods

Food	Serving	Vitamin B12 (mcg)	Percent Daily Value
Clams	3 oz.	84.1	1,402
Salmon	3 oz.	4.8	80
Tuna, canned	3 oz.	2.5	42
Breakfast cereals, fortified	1 serving	1.5	25
Beef, top sirloin	3 oz.	1.4	23
Milk, lowfat	8 fl oz.	1.2	18
Yogurt, lowfat	8 oz.	1.1	18
Cheese, swiss	1 oz.	0.9	15
Egg	1 large	0.6	10

Dietary Fact Sheet: Vitamin B_{12}. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/VitaminB12-HealthProfessional/. Updated February 11, 2016. Accessed October 28, 2017.

Vitamin B12 Deficiency and Excess

When there is a deficiency in vitamin B_{12}, inactive folate (from food) is unable to be converted to active folate and used in the body for the synthesis of DNA. However, folic acid from supplements or fortified foods is available to be used as active folate in the body without vitamin B_{12}. Therefore, if there is a deficiency in vitamin B_{12}, macrocytic anemia may occur. Vitamin B_{12} deficiency also results in nerve degeneration and abnormalities that can often precede the development of anemia. These include a decline in mental function and burning, tingling, and numbness of legs. These symptoms can continue to worsen, and deficiency can be fatal.[4]

The most common cause of vitamin B_{12} deficiency is the condition of inadequate intrinsic factor production that leads to poor vitamin B_{12} absorption, resulting in pernicious anemia. This condition is common in people over the age of 50, because

production of intrinsic factor decreases with age. Pernicious anemia is treated by large oral doses of vitamin B_{12} or by putting the vitamin under the tongue (sublingual), where it is absorbed into the bloodstream without passing through the intestine. In patients that do not respond to oral or sublingual treatment, vitamin B_{12} is given by injection.

Because vitamin B_{12} is found only in animal-source foods, a strict vegetarian diet can result in cases of vitamin B_{12} deficiency. Therefore, careful dietary planning to include fortified sources or supplements of vitamin B_{12} is important to prevent deficiency in a vegan diet.

No toxicity of vitamin B_{12} has been reported. Because of the low risk for toxicity, a tolerable upper intake level (UL) has not been established for vitamin B_{12}.[4]

Vitamin K

Vitamin K refers to a group of fat-soluble vitamins that are similar in chemical structure. Vitamin K is critical for blood function acting as coenzymes which play an essential role in blood coagulation (aka blood clotting). Blood-clotting proteins are continuously circulating in the blood. Upon injury to a blood vessel, platelets stick to the wound forming a plug. Without vitamin K, blood would not clot.

A deficiency in vitamin K causes bleeding disorders. It is relatively rare, but people who have liver or pancreatic disease, celiac disease, or malabsorption conditions are at higher risk for vitamin K deficiency. Signs and symptoms include nosebleeds, easy bruising, broken blood vessels, bleeding gums, and heavy menstrual bleeding in women. The function of the anticoagulant drug warfarin is impaired by excess vitamin K intake from supplements. Calcium additionally plays a role in activation of blood-clotting proteins.

Bone Health

Vitamin K is also required for maintaining bone health. It modifies the protein osteocalcin, which is involved in the bone remodeling process. All the functions of osteocalcin and the other vitamin K-dependent proteins in bone tissue are not well understood and are under intense study. Some studies do show that people who have diets low in vitamin K also have an increased risk for bone fractures.

Dietary Reference Intake and Food Sources for Vitamin K

The AI of vitamin K for adult females is 90 micrograms per day, and for males it is 120 micrograms per day. A UL for vitamin K has not been set. The Food and Nutrition Board (FNB) has not established an UL for vitamin K because it has a low potential for toxicity. According to the FNB, “no adverse effects associated with vitamin K consumption from food or supplements have been reported in humans or animals.”

Institute of Medicine. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: National Academy Press; 2001.

Table : Dietary Reference Intakes for Vitamin K

Age Group	RDA (mcg/day)
Infants (0–6 months)	2.0*
Infants (6–12 months)	2.5*
Children (1–3 years)	30
Children (4–8 years)	55
Children (9–13 years)	60
Adolescents (14–18 years)	75
Adult Males (> 19 years)	120
Adult Females (> 19 years)	90

Age Group	RDA (mcg/day)
* denotes Adequate Intake	

Source: Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc. Institute of Medicine. www.iom.edu/Reports/2001/Dietary-Reference-Intakes-for-Vitamin-A-Vitamin-K-Arsenic-Boron-Chromium-Copper-Iodine-Iron-Manganese-Molybdenum-Nickel-Silicon-Vanadium-and-Zinc.aspx. Published January 9, 2001. Accessed October 10, 2017.

Dietary Sources of Vitamin K

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

Table : Dietary Sources of Vitamin K

Food	Serving	Vitamin K (mcg)	Percent Daily Value
Broccoli	½ c.	160	133
Asparagus	4 spears	34	28
Cabbage	½ c.	56	47
Spinach	½ c.	27	23
Green peas	½ c.	16	13
Cheese	1 oz.	10	8
Ham	3 oz.	13	11
Ground beef	3 oz.	6	5
Bread	1 slice	1.1	<1
Orange	1 e.	1.3	1

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9.5: Antioxidant Vitamins — C and E

The market is flooded with advertisements for “super antioxidant” supplements teeming with molecules that block free radical production, stimulate the immune system, prevent cancer, and reduce the signs of aging. Based on the antioxidant-supplement industry’s success, the general public appears to believe these health claims. However, these claims are not backed by scientific evidence; rather, there is some evidence suggesting some dietary supplements can actually cause harm. Scientific evidence supports the consumption of antioxidant-rich foods as a method of reducing the risk of chronic disease, but 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 food that is beneficial.

There are many different antioxidants in food, including the mineral, selenium, which is one of the major antioxidants. However, the antioxidants you may be the most familiar with are vitamins.

In this section, we will review how particular antioxidants function in the body, learn how they work together to protect the body against free radicals, and explore the best nutrient-rich dietary sources of antioxidants. In our discussion of antioxidant vitamins, we will focus on vitamins C and E.

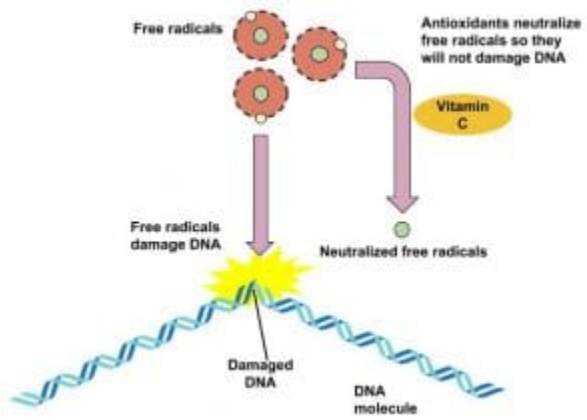


Figure : Antioxidants’ Role. Image by Allison Calabrese / CC BY 4.0

Antioxidant Chemicals Obtained from the Diet

Table : Some Antioxidants Obtained from Diet and Their Related Functions

Antioxidant	Antioxidant Source	Antioxidant Function
Vitamin C	Oranges, grapefruit	Protects DNA, RNA, proteins, and lipids, aids in regenerating vitamin E
Vitamin E	Sunflower seeds, almonds, sunflower oil	Protects cellular membranes, prevents glutathione depletion
Carotenoids	Pumpkin, carrots	Free radical scavenger

What Are Antioxidants, and Why Do We Need Them?

Recall that atoms are composed of a nucleus, which contains neutrons and protons, and electrons, which orbit the nucleus. Atoms are most stable when they have an even number of electrons, so that they can orbit the nucleus in pairs.

An atom or group of atoms with an unpaired electron is called *a*free radical. Free radicals are inherently unstable and highly reactive. They steal electrons from other molecules in order to stabilize themselves, but in doing so, they create additional free radicals. This electron-grabbing is called ***oxidation*** and can set up a chain reaction, creating new free radicals and damaging

important molecules along the way, similar to how one falling domino can bring down countless more.

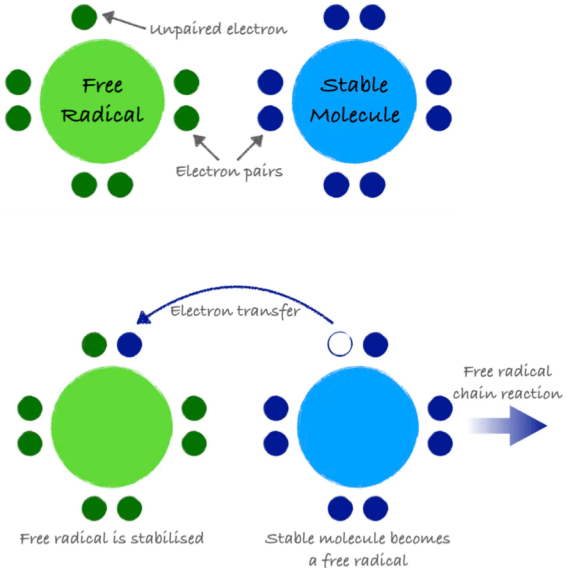


Figure 8.12. A free radical is a molecule with an unpaired electron. It can steal electrons from a stable molecule, creating a new free radical and initiating a chain reaction.

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

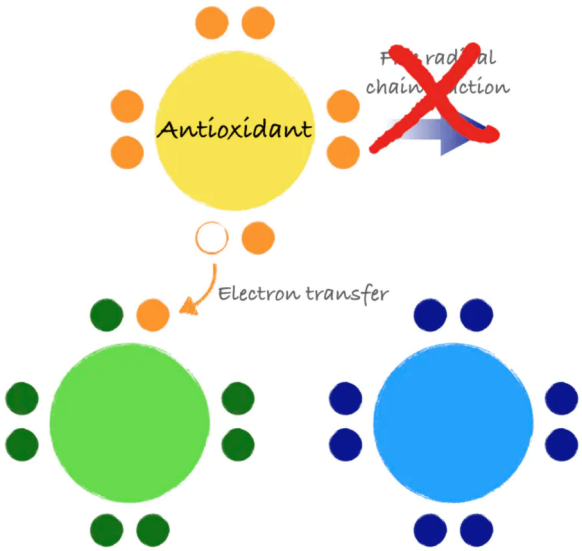


Figure 8.13. Antioxidants stabilize free radicals by donating electrons, preventing the chain reaction that can create more free radicals.

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

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

However, **too many free radicals and not enough protection from antioxidants creates a situation called *oxidative stress.*** Free radical-induced damage, when left unrepaired, destroys lipids, proteins, RNA, and DNA, and can contribute to disease. Oxidative stress has been implicated as a contributing factor to cancer, cardiovascular disease, arthritis, diabetes, kidney disease, Alzheimer's disease, Parkinson's disease, and eye diseases such as cataracts.[2]

Substances and energy sources from the environment can add to or accelerate the production of free radicals within the body. Exposure to UV radiation (e.g., from sunlight), air pollution, tobacco 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 is associated with the development of chronic diseases, and eating a diet rich in antioxidant-containing foods like fruits, vegetables, and whole grains seems to protect against many of these same diseases. It was thus natural for researchers to hypothesize that taking antioxidants in supplement form might also offer protection from these diseases. However, several decades of research investigating this hypothesis have revealed disappointing results. Not only have these studies shown that antioxidant supplements generally aren't beneficial, some have shown that they can cause health risks. For example, high doses of beta-carotene increased the risk of lung cancer in smokers, and high doses of vitamin E increased the risk of prostate cancer in men. Antioxidant supplements may also interact with other medications, further emphasizing the importance of talking with your doctor before taking supplements.[2]

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

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

Vitamin C

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

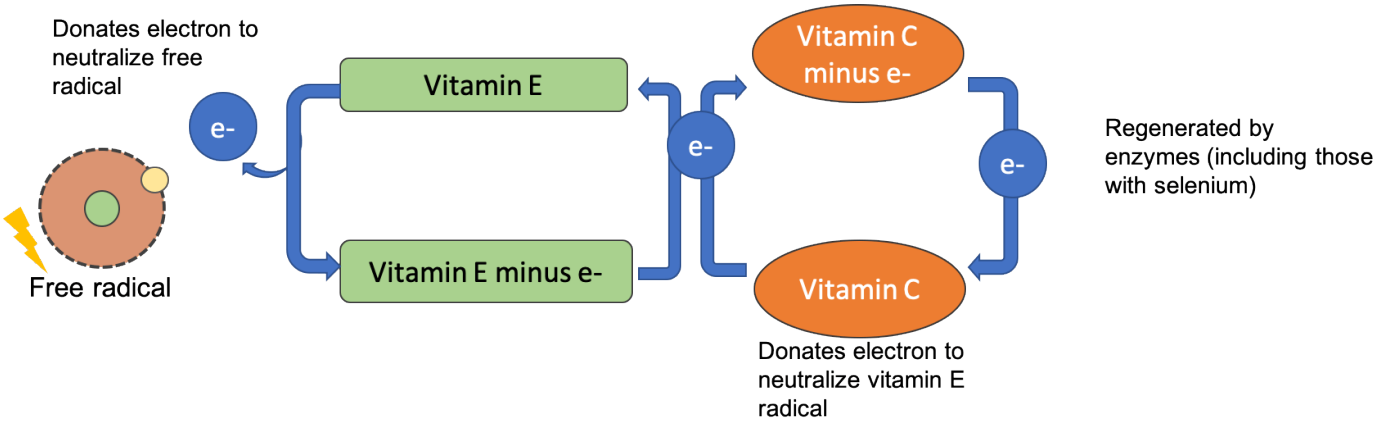


Figure 8.15. After vitamin E donates an electron to neutralize a free radical, it can be regenerated by an electron from vitamin C. Vitamin C is then regenerated by antioxidant enzymes.

In addition to its role as an antioxidant, vitamin C is a required part of several enzymes involved in the synthesis of ***collagen***, a protein important to the strength and structure of muscles, bones, tendons, ligaments, connective tissue, and skin. Vitamin C is

also required to synthesize neurotransmitters important for signaling in the brain, some hormones, and amino acids. It also plays a role in immune function and improves the absorption of dietary iron.

The body's vitamin C status is tightly controlled to maintain steady tissue and plasma concentrations. This means that if you consume high doses of vitamin C, you'll absorb less from the intestine and excrete more in urine to prevent excessive concentrations in the body. Vitamin C is not stored in any significant amount in the body, but once it has reduced a free radical, it is very effectively regenerated and therefore can exist in the body as a functioning antioxidant for many weeks.

Vitamin C and Colds

Interest in using vitamin C to prevent or treat the common cold began with the work of Dr. Linus Pauling, who promoted high-dose supplements. Since then, many studies have tested its effectiveness. A 2013 analysis by Hemilä and Chalker of over 50 studies found that regular vitamin C supplementation (0.25–2 g/day) did not reduce the number of colds in the general population but did cut the risk in people under intense physical stress, like athletes or soldiers in cold environments. Regular supplementation also slightly shortened the duration of colds — by about 14% in children and 8% in adults — but taking vitamin C after symptoms started did not seem to help. A 2023 study by the same investigators found that vitamin C reduced the severity of cold symptoms by 15%, especially shortening the duration of more severe symptoms. There is also some early evidence suggesting that vitamin C might help reduce asthma symptoms triggered by respiratory infections, but more research is needed to confirm this.

- Hemilä H, Chalker E. *Vitamin C for preventing and treating the common cold*. **Cochrane Database Syst Rev.** 2013 Jan 31;2013(1):CD000980. doi:10.1002/14651858.CD000980.pub4 (Cochrane)

- Hemilä H, Chalker E. *Vitamin C reduces the severity of common colds: a meta-analysis*. **BMC Public Health.** 2023 Dec 11;23(1):2468. doi:10.1186/s12889-023-17229-8 (bmcpublichealth.biomedcentral.com)

Food Sources of Vitamin C

Fruits and vegetables are great sources of vitamin C. Some of the best sources include bell pepper, citrus, broccoli, strawberries, Brussels sprouts, and cantaloupe.[4]

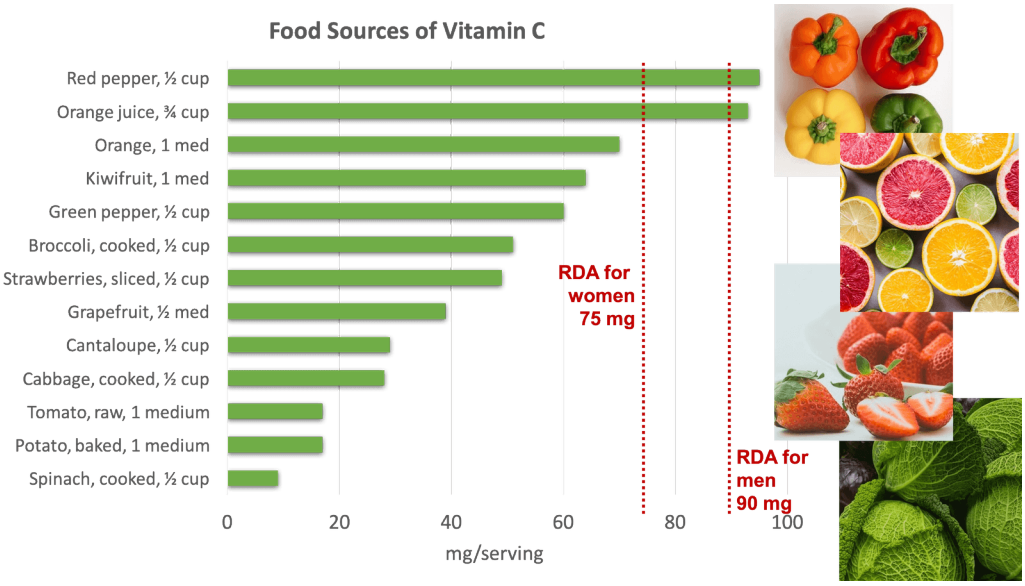


Figure 8.16. Dietary sources of vitamin C. Source: NIH *Office of Dietary Supplements*

Because vitamin C is water-soluble, it leaches away from foods considerably during cooking, freezing, thawing, and canning. Up to 50% of vitamin C can be boiled away. Therefore, eating fruits and vegetables raw or lightly steamed maximizes the vitamin C value of these foods.

Vitamin C Deficiency and Toxicity

The classic condition caused by vitamin C deficiency is ***scurvy***. The signs and symptoms of scurvy include skin disorders, bleeding gums, joint pain, and weakness—all of which may be related to vitamin C's role in collagen synthesis. Additional symptoms of scurvy include abnormally-thickened skin, fatigue, depression, iron deficiency anemia, and increased susceptibility to infections.

In the past, scurvy was common among sailors on long ocean voyages, whose diets were completely lacking in fruits and vegetables for many months. In the mid-1700s, British Navy surgeon Sir James Lind's experiments revealed that citrus fruits and juices could prevent scurvy in sailors. British sailors were often referred to as "limeys," as they carried sacks of limes onto ships to prevent scurvy. It was not until 1932 that scientists showed that vitamin C was the essential nutrient involved in this cure.

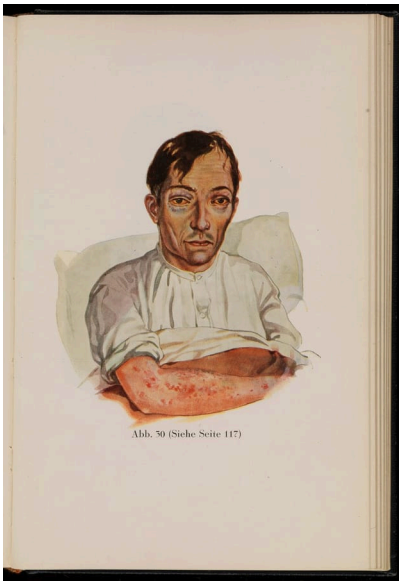


Figure 8.17. This drawing of a sailor with scurvy, from the 1929 edition of "Kranken-Physiognomik" by von K. H. Baumgärtner, shows common effects of the disease, including sunken eyes and skin lesions.

Scurvy is prevented by even a low intake of fruits and vegetables, and it takes at least a month of consuming very little or no vitamin C for scurvy symptoms to develop. Thus, scurvy is rare in developed countries today. Diet surveys show that most Americans meet the RDA for vitamin C. When vitamin C deficiency occurs today, it is in people who consume very limited food variety, such as those with mental illness, people who abuse alcohol or drugs, people on very restrictive diets, and impoverished people with limited fruit and vegetable access. People who smoke also require more vitamin C to counter the free radicals generated by smoking.

The risk of vitamin C toxicity from foods is essentially nonexistent, because the body can adjust intestinal absorption and urinary excretion to maintain a healthy vitamin C level. However, high doses of vitamin C from supplements have been reported to cause numerous problems, including gastrointestinal upset and diarrhea. To prevent these discomforts, the UL for vitamin C is set at 2,000 milligrams per day for adults, more than twenty times the RDA.

At very high doses in combination with iron, vitamin C has sometimes been found to increase oxidative stress, reaffirming that getting your antioxidants from foods is better than getting them from supplements. There is also some evidence that taking vitamin C supplements at high doses increases the likelihood of developing kidney stones; however, this effect is most often observed in people that already have multiple risk factors for kidney stones.

Vitamin E

When we talk about vitamin E, we're actually referring to 8 chemically similar substances, of which alpha-tocopherol appears to be the most potent antioxidant. Because vitamin E is fat-soluble, its antioxidant capacity is especially important to lipids, including those in cell membranes and lipoproteins. For example, free radicals can oxidize LDL cholesterol (stealing an electron from it), and it is this damaged LDL that lodges in blood vessels and forms the fatty plaques characteristic of atherosclerosis, increasing the risk of heart attack, stroke, and other complications of cardiovascular disease.

After alpha-tocopherol interacts with a free radical it is no longer capable of acting as an antioxidant unless it is enzymatically regenerated. Vitamin C helps to regenerate some of the alpha-tocopherol, but the remainder is eliminated from the body. Therefore, to maintain vitamin E levels, you ingest it as part of your diet.

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

Food Sources of Vitamin E

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

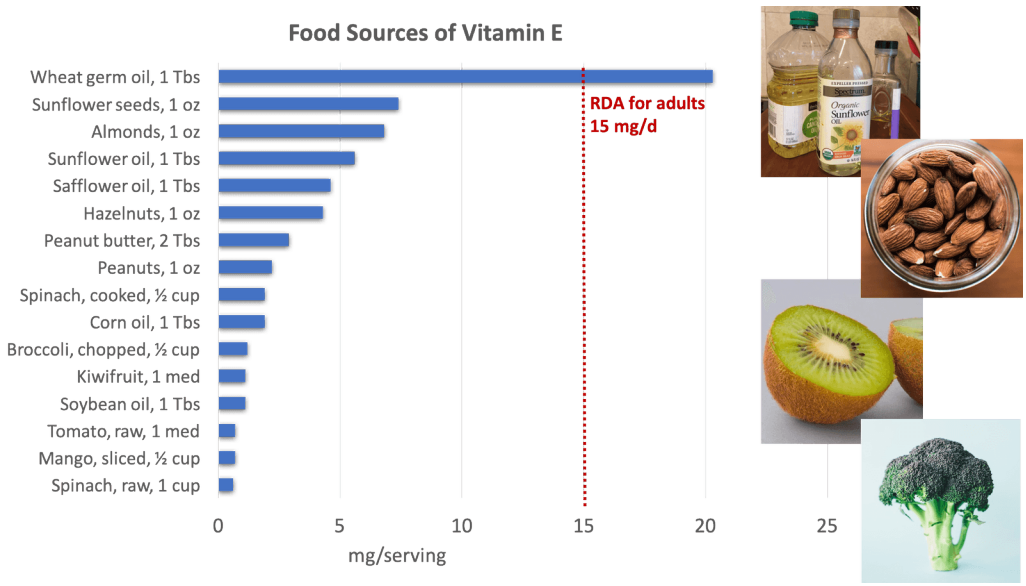


Figure *8.14. Dietary sources of vitamin E. Source: NIH Office of Dietary Supplements*

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

Vitamin E Deficiency and Toxicity

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

Studies have not found any risks of consuming vitamin E in foods. The UL for vitamin E is set at 1,000 mg for adults, far above the RDA of 15 mg and far higher than could naturally be obtained from food. These amounts are available in supplement form, however. As mentioned, high-dose vitamin E supplements were shown to increase the risk of prostate cancer in men (Klein et al, 2011). Other studies have found that high-dose vitamin E supplements are associated with an increased risk of hemorrhage, stroke, and death (Miller et al, 2005; Schürks et al, 2010).

- Klein EA, Thompson IM Jr, Tangen CM, et al. *Vitamin E and the Risk of Prostate Cancer: The Selenium and Vitamin E Cancer Prevention Trial (SELECT).* JAMA. 2011;306(14):1549-1556. doi:10.1001/jama.2011.1437 (PubMed)

- Miller ER 3rd, Pastor-Barriuso R, Dalal D, Riemersma RA, Cook NR, Appel LJ. *Meta-analysis: high-dosage vitamin E*

supplementation may increase all-cause mortality. Ann Intern Med. 2005;142(1):37-46. doi:10.7326/0003-4819-142-1-200501040-00110 (DrugBank)

- Schürks M, Glynn RJ, Rist PM, Tzourio C, Kurth T. *Effects of vitamin E on stroke subtypes: meta-analysis of randomised controlled trials.* BMJ / British Medical Journal. 2010;341:c5702. doi:10.1136/bmj.c5702 (PMC)

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9.6: Vitamins and Gene Expression — A and D

Vitamins A and D are included in this chapter on Vitamins and Gene Expression because they function as regulators of gene activity. Unlike vitamins that serve primarily as enzyme cofactors, vitamins A and D exert their effects by interacting with receptors in a cell's nucleus that influence the transcription of specific genes. Through these mechanisms, they play key roles in processes such as cell differentiation, immune function, and calcium homeostasis.

Vitamin A

In this section, we'll cover the functions, food sources, and signs of deficiency and toxicity for vitamin A and carotenoids such as beta-carotene, which can be converted to vitamin A.

Vitamin A is a generic term for a group of similar compounds called retinoids. ***Retinol*** is the form of vitamin A found in animal-derived foods, and it is converted in the body to the biologically active forms of vitamin A: retinal and retinoic acid. The dietary retinol found in animal-derived foods is called ***preformed or active vitamin A***.

This differentiates it from ***beta-carotene*** and other ***carotenoid*** compounds, which are brightly-colored yellow, orange, and red pigments synthesized by plants. These are called ***provitamin*** A carotenoids, because they can be converted to vitamin A in the body. Among the carotenoids, beta-carotene is most efficiently converted to vitamin A. If you look at the beta-carotene molecule, you can see that it looks like two retinol molecules connected together. Enzymes in the intestine and liver can cleave the beta-carotene molecule in half, creating two new molecules of vitamin A.

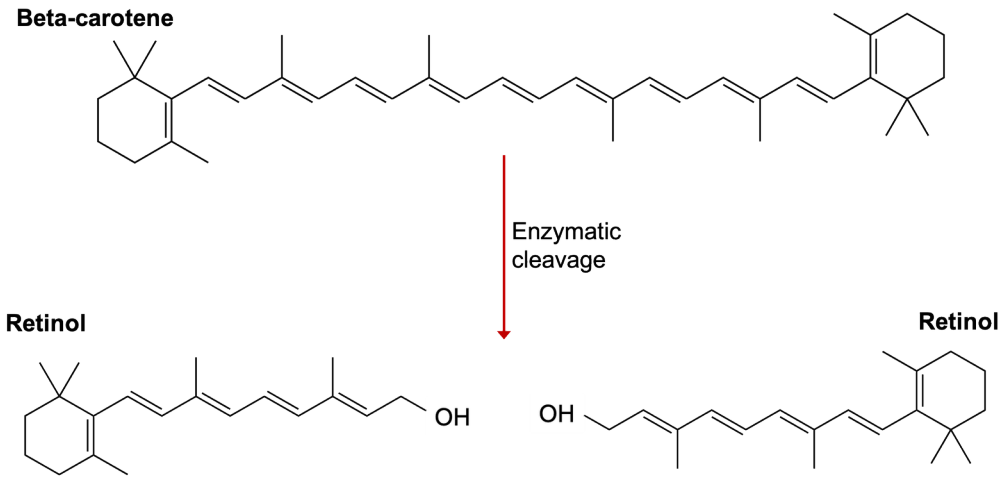


Figure 8.19. One molecule of beta-carotene can be enzymatically cleaved to 2 molecules of vitamin A.

As with other fat-soluble vitamins, vitamin A is packaged into chylomicrons in the enterocytes of the small intestine and then transported to the liver. The liver stores and exports vitamin A as needed; it is released into the blood bound to a retinol-binding protein, which transports it to cells. Beta-carotene can be converted into vitamin A in the intestine, or it can be absorbed intact, packaged in chylomicrons, and then transported around the body in lipoproteins. Beta-carotene and other carotenoids that aren't converted to vitamin A can also act as powerful antioxidants and have other helpful functions in the body, which may in part explain the health benefits of a diet rich in fruits and vegetables.

Vitamin A and Gene Expression

Vitamin A is also required for normal ***cellular differentiation***, the process by which cells change from stem cells to more specialized cells with specific structure and function. Cellular differentiation is important in every tissue of the body, but if there is a shortage of vitamin A, the eye is one of the first areas to be impacted. Specialized cells in the lining of the eyes produce

mucus and tears, which keep eyes moist and lubricated. When the mucus-secreting cells die, they need to be replaced with new cells. If the body is deficient in vitamin A, those new cells don't differentiate normally, resulting in dry eyes, a condition called ***xerophthalmia***. Instead of producing mucus, these dysfunctional cells produce a protein called keratin. ***Keratin*** is a hard, structural protein that is found in nails, hair, and the outer layer of skin, and you can imagine the problems it causes when it accumulates in the eye. Instead of a moist, well-lubricated eye, keratin makes the eye hard and dry, resulting in clouded vision.



Figure 8.21. A child with xerophthalmia caused by vitamin A deficiency, demonstrating cloudiness on the surface of the eye.

Vitamin A's role in cellular differentiation also makes it critical to cells around the body involved in normal growth, development, reproduction, and immune function. All of these processes require cells to develop in specific ways at specific times, and vitamin A helps to orchestrate these processes. For example, embryonic development requires stem cells to differentiate into specific types of cells to form new organs, and timing is critical.

Vitamin A and Vision

Vision is one of our five basic senses, and unless you've experienced vision loss, it's hard to imagine life without sight. Vitamin A plays a key role in vision and eye health.

The retinoids are aptly named, as their most notable function is in the retina of the eye. 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***. Rhodopsin is especially important to our ability to see in low-light conditions. When light hits rhodopsin in the eye, a nerve signal is sent to the brain, allowing us to detect that light. A person that is deficient in vitamin A has less rhodopsin pigment in the eye and is therefore less able to detect low-level light. **This makes it more difficult to see at night, a condition referred to as *night blindness***, and this is one of the first signs that a person is deficient in vitamin A.

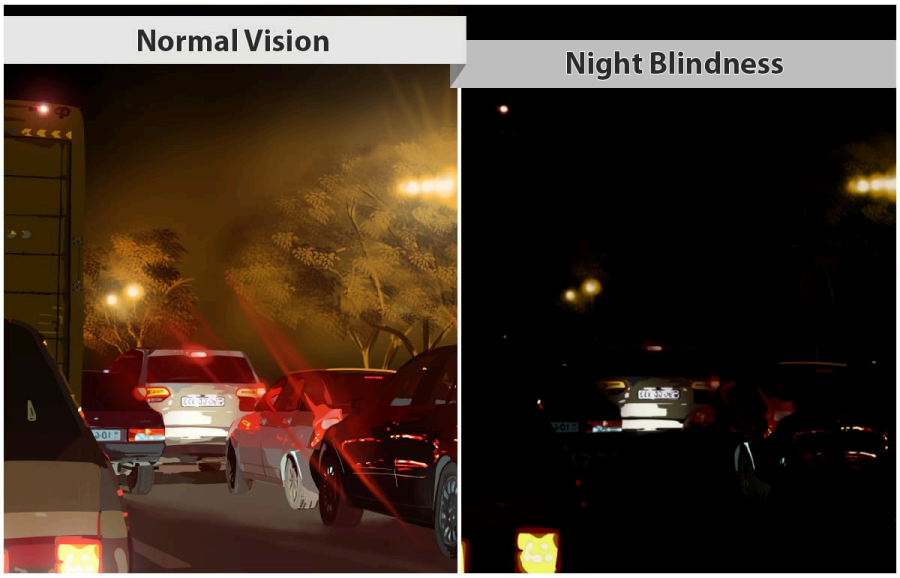


Figure 8.20. A depiction of the vision of a person suffering from night blindness, in which there is inadequate rhodopsin for detection of light.

A deficiency in vitamin A can thus impair vision in two ways:

1. Development of night blindness due to a lack of the pigment rhodopsin
2. Development of xerophthalmia, or dry eyes, caused by abnormal cellular differentiation

Night blindness is usually the first sign of a vitamin A deficiency, followed by xerophthalmia and clouded vision. If the deficiency persists, the damage from keratin in the lining of the eye can cause permanent blindness.

Food Sources of Vitamin A and Carotenoids

Preformed vitamin A is found only in animal-derived foods. The best food sources are liver and fish oils, as vitamin A is fat-soluble and stored in fatty tissues. Smaller amounts can be found in other animal products, such as meat, eggs, and dairy products.

Provitamin A carotenoids such as beta-carotene are mostly found in fruits and vegetables. Carotenoids are brightly-colored pigments, so vibrant color is a good indicator of their presence. Top sources include orange and yellow vegetables such as carrots, sweet potatoes, and pumpkins (beta-carotene is a bright orange pigment), bell peppers, fruit, leafy green vegetables, and some vegetable oils. Some carotenoids can also be found in animal-derived foods. For example, the yellow color of egg yolk and butter comes from carotenoids absorbed from the diets of the hens and cows, respectively.

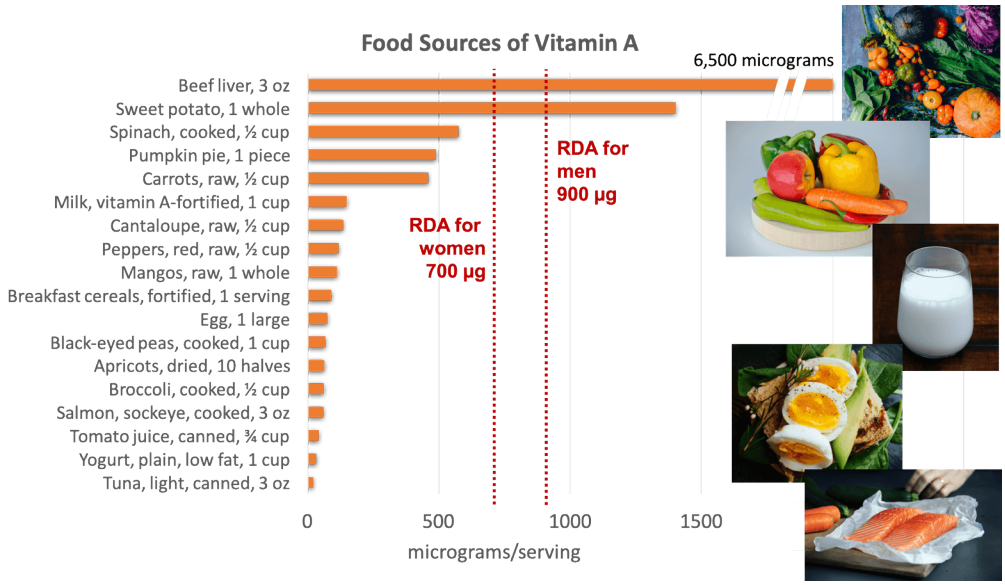


Figure 8.22. Food sources of vitamin A. Source: *NIH Office of Dietary Supplements* .

Deficiency and Toxicity of Vitamin A and Carotenoids

The main symptoms of vitamin A deficiency are xerophthalmia, night blindness, and increased susceptibility to infections. Another symptom is ***hyperkeratosis***, which occurs when cells in the skin overproduce the protein keratin (similar to what happens in the eye with xerophthalmia) causing the skin to become rough and irritated.

Vitamin A deficiency is rare in developed countries, but globally, it is the leading cause of preventable blindness in children. It is caused by malnutrition related to consumption of inadequate diets predominantly based on staple grains and lacking in animal products, fruits, vegetables, and fat, which increases absorption of vitamin A. According to the World Health Organization, an estimated 250,000 to 500,000 children lose their sight each year due to vitamin A deficiency, and half of them die within a year of developing blindness, likely due to infection.[2] According to UNICEF, 30% of children under 5 have vitamin A deficiency in the world, but rates are as high as 44% and 48% in south Asia and sub-Saharan Africa, respectively.[4]

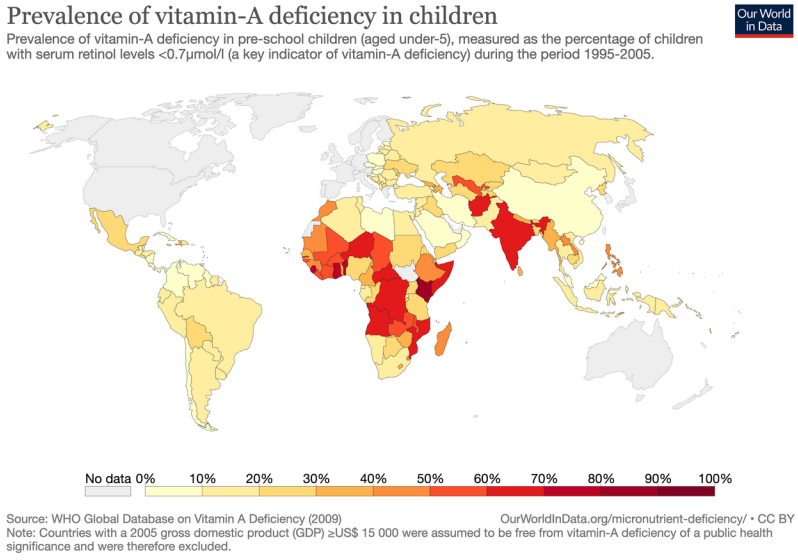


Figure 8.23. The worldwide prevalence of vitamin A deficiency in 1995-2005, based on World Health Organization data.

Vitamin A toxicity causes dry, itchy skin, loss of appetite, dizziness, nausea, swelling of the brain, and joint pain. In the most severe cases, it can cause liver damage, coma, and death. Vitamin A toxicity is almost always caused by taking supplements in

doses above the UL of 3,000 micrograms per day for substantial periods. These high doses would not be found in a normal diet, although vitamin A toxicity has been observed in Arctic explorers who ate large amounts of bear and seal liver.[4]

Consuming excessive amounts of vitamin A during pregnancy can also cause birth defects, so pregnant people should pay close attention to vitamin A contained in supplements. In addition, some synthetic forms of vitamin A (Retin-A and Accutane, for example) are used as acne treatments and should never be used during pregnancy due to the risk of birth defects.

Unlike preformed vitamin A, beta-carotene and other carotenoids do not seem to cause birth defects or other major toxicity effects in high doses. This is because the body doesn't convert beta-carotene to vitamin A if it already has excessive amounts of vitamin A. Because it doesn't cause toxicity, beta-carotene is usually used as the source of vitamin A in prenatal multivitamin supplements.

Beta-carotene that isn't converted to vitamin A is absorbed intact in the intestine. When high levels of beta-carotene are consumed in the diet, it can have the unusual effect of making a person's skin appear to be yellow or orange. The color change doesn't seem to be harmful, and normal skin tone returns once the person stops consuming so much beta-carotene. However, studies have shown that long-term consumption of high-dose beta-carotene supplements have been linked to increased rates of cancer and death, so it's best to get beta-carotene from food rather than supplements.

Vitamin D

Vitamin D is unique among the vitamins because we can synthesize most of what we need in our skin. Sunlight is an essential ingredient in this process, so vitamin D is sometimes called the "sunshine vitamin." However, this should not be taken as an endorsement of regular sunbathing as a means of achieving adequate vitamin D levels. Chronic sun exposure contributes substantially to skin damage, accelerating the visible hallmarks of aging (e.g., fine lines, deep wrinkles, loss of elasticity, and pigmentary changes) via UV-induced DNA damage, reactive oxygen species, and degradation of collagen and elastin in the dermis. Additionally, sun exposure increases risk for skin cancer, and the amount of vitamin D synthesized in the body is often not enough to meet our needs, especially in the winter months.

The hazards of UV exposure — namely acceleration of skin aging and elevation of skin cancer risk — mean that sun exposure is generally not considered a safe or reliable route to meet vitamin D requirements. Most people will need to depend (at least in part) on dietary sources or supplements to maintain optimal vitamin D status.

Vitamin D synthesis in the skin begins with the conversion of cholesterol to 7-dehydrocholesterol. Then, in the presence of ultraviolet (UV) rays from sunlight, 7-dehydrocholesterol is converted to vitamin D_3 (also called ***cholecalciferol***), which is transported to the liver by a binding protein.

In dietary sources, vitamin D may be present in the form of vitamin D_3 from animal products or vitamin D_2 (also called ***ergocalciferol***), made by plants, mushrooms, and yeast. Dietary vitamin D_2 and vitamin D_3 are transported to the liver via chylomicrons and then taken up in chylomicron remnants.

Vitamins D_2 and D_3 are both inactive until they undergo two ***hydroxylations***—chemical reactions that add a hydroxyl (-OH) group. The first hydroxylation occurs in the liver, creating ***calcidiol***. This is the circulating form of vitamin D and the form measured in blood to assess a person's vitamin D status. The second hydroxylation occurs in the kidneys and forms ***calcitriol,*** the biologically active form of vitamin D.

Vitamin D and Gene Expression

Vitamin D has many functions in the body. Cells throughout the body have vitamin D receptors in their nuclei, and by binding to these receptors, vitamin D is thought to regulate the expression of hundreds of genes. Specifically, vitamin D is known to play important roles in regulating cellular differentiation and growth, immunity, insulin secretion, and blood pressure. Studies have found *correlations* between low circulating vitamin D levels and increased risks of chronic diseases, including cancer, diabetes, cardiovascular disease, and multiple sclerosis. However, it has been difficult to determine if a lack of vitamin D actually contributes to the *cause* of these diseases, and research in this area is ongoing.[1]

Role in Blood Calcium Regulation

When calcium is covered later in this textbook, vitamin D will mentioned for its role in the regulation of blood calcium. Active vitamin D increases the absorption of both calcium and phosphorus in the intestine, as well as working with parathyroid hormone (PTH) to reduce calcium loss in the urine and stimulate release of calcium and phosphorus from the bone. In these ways, vitamin D plays a critical role in both maintaining blood calcium homeostasis and enhancing the supply of calcium and phosphorus for bone mineralization. Vitamin D deficiency results in poor bone mineralization, with serious consequences in both children and adults, as we'll discuss later on this page.

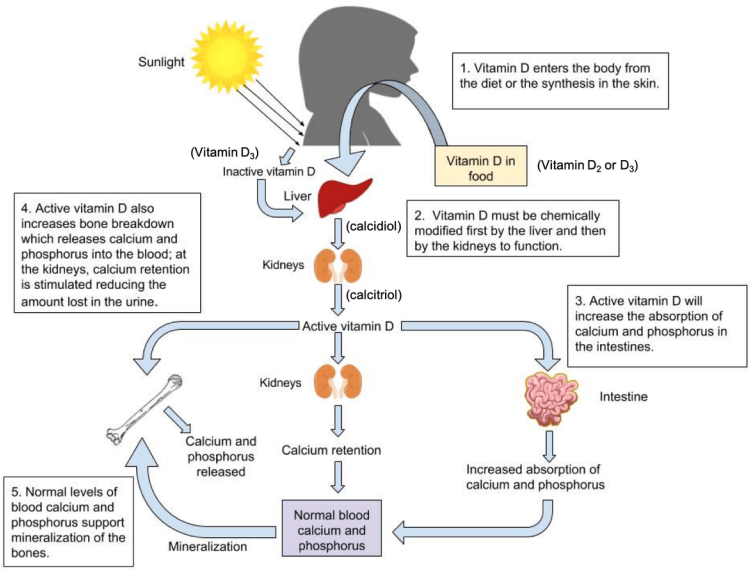


Figure 9.11. *Vitamin D can be synthesized in the skin (vitamin D $_3$) or provided in the diet (vitamin D $_2$ or D $_3$). It is converted by reactions occurring first in the liver (making calcidiol) and then kidney (making calcitriol, the active form). Once active, vitamin D works in several ways to ensure blood calcium homeostasis and enhance the availability of calcium for bone mineralization.*

Sunlight as a Source of Vitamin D

In most people, vitamin D synthesis in the skin provides a significant portion of their body's needs, and a little sun exposure can go a long way. Vitamin D researchers suggest that most people need between 5 and 30 minutes of sun exposure between 10 AM and 3 PM, at least twice per week, in order to synthesize adequate vitamin D. However, any factor that decreases exposure to UV rays can interfere with vitamin D synthesis, including the following:[2]

- **Geographic latitude and season.** Your location on Earth and the time of the year affects your exposure to UV radiation from the sun. Exposure to UV light is greatest at the equator and declines as you move further north or south. Likewise, in the summer months, the sun is directly overhead for a greater part of the day, so you have more opportunities to synthesize vitamin D. In the winter, the sun stays lower in the sky, day length is shorter, and cloud cover is more likely to block the sun's rays, all of which decrease opportunities to synthesize vitamin D. North of about 35 degrees latitude, vitamin D synthesis is inadequate for at least a few months during the winter, because the sun simply doesn't get high enough in the sky to provide enough UV radiation on earth's surface. For example, in Boston and at the California-Oregon border (42nd parallel north), vitamin D synthesis occurs only from March until October. However, in Los Angeles (34th parallel north), vitamin D synthesis occurs year round. Ozone and air pollution can also block UV rays and decrease vitamin D synthesis.
- **Skin pigmentation.** Darker skin pigmentation, caused by greater melanin production in the skin, decreases UV light absorption. This helps to protect the skin from damage from UV radiation—a helpful adaptation for those living closer to the equator—but it also reduces synthesis of vitamin D. People with darker skin pigmentation need to spend more time in the sun in order to synthesize the same amount of vitamin D as lighter-skinned people.
- **Age.** The efficiency of vitamin D synthesis declines with age. In addition, older adults often spend less time outside so may receive less exposure to sunlight.
- **Sun-protective behavior.** While some UV light exposure is needed to synthesize vitamin D, UV radiation is also carcinogenic, and too much exposure increases the risk of skin cancer. It's wise to protect your skin from UV radiation by

applying sunscreen, covering up with clothing and a hat, finding shade, and avoiding sun exposure in the middle of the day. People who are highly vigilant in these sun-protective behaviors or simply aren't able to go outside during the day (UV rays don't penetrate glass) may not get enough UV light for vitamin D synthesis.

With so many factors affecting UV radiation exposure, many people are unable to synthesize enough vitamin D for at least part of the year. Because vitamin D is fat-soluble, liver and adipose storage can supply the body for a while. Beyond that, dietary sources and supplements might be needed to meet the vitamin D requirement.[2]

Dietary Sources of Vitamin D

Only a few foods are naturally good sources of vitamin D. These include fatty fish such as salmon, tuna, and mackerel, as well as fish liver oil (e.g., cod liver oil). Smaller amounts are found in egg yolks, cheese, and beef liver. Additionally, some mushrooms grown in UV light can be a good source of vitamin D.

Most cow's milk is fortified with vitamin D in the U.S. and Canada, but other dairy products such as ice cream and cheese are not. Fortified orange juice, soymilk and other plant-based beverages, and breakfast cereal can all contribute to dietary intake of vitamin D, although amounts added vary significantly between products.[2]

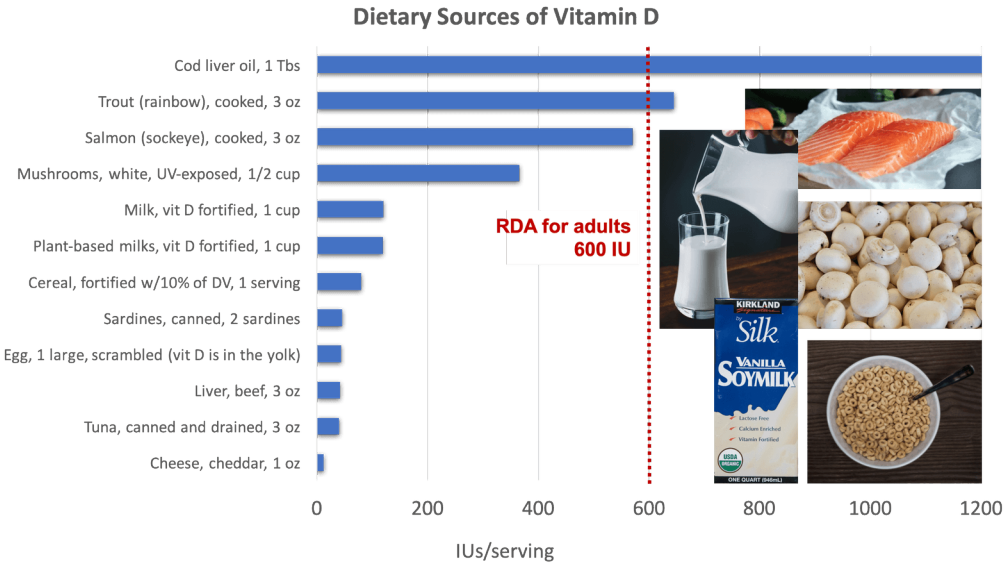


Figure 9.12. Dietary sources of vitamin D. Source: Examples of good sources pictured include salmon, milk, mushrooms, fortified soy milk, and fortified cereal. NIH *Office of Dietary Supplements*

Both vitamin D_2 and D_3 supplements are also available. Some studies have found D_3 to be more effective at raising circulating vitamin D levels, but others haven't found a difference in efficacy of the two forms.[1,2] Human breast milk doesn't contain adequate vitamin D, so the American Academy of Pediatrics recommends that breastfed infants receive a supplement with 400 IU of vitamin D per day until they are weaned to vitamin D-fortified formula or cow's milk. A vitamin D supplement may also be recommended for older children and adults, depending on dietary intake and sun exposure, but this should be discussed with a healthcare provider.

Vitamin D Deficiency and Toxicity

In children, vitamin D deficiency causes ***rickets***, a disease in which the bones are soft, weak, and deformed. Rickets was very common in the U.S. until the 1930s, when milk processors were asked to add vitamin D to cow's milk. Milk fortification has virtually eliminated rickets from the U.S. and other developed countries. However, rickets does still occur in breastfed infants and children raised on vegan diets who aren't provided with other sources of vitamin D, particularly if they have darker skin pigmentation.[1,3]



Figure 9.13. Vitamin D deficiency in children causes rickets, a disease in which inadequate vitamin D leads to soft, weak, and deformed bones.

In adults, vitamin D deficiency causes ***osteomalacia***, characterized by softening of bones, reduced bone mineral density, and increased risk of osteoporosis. Because bones are continuously remodelled throughout the lifespan, inadequate vitamin D limits the calcium available to continue to rebuild bone tissue. Vitamin D deficiency can also cause bone pain, as well as muscle weakness and pain, symptoms that can increase the risk of falling and fractures, particularly in older adults.[2]

Although vitamin D toxicity is rare, taking excessive amounts of vitamin D in supplement form can lead to ***hypercalcemia***, or high blood calcium. Hypercalcemia can cause kidney damage and calcium deposits to develop in soft tissues such as the kidneys, blood vessels, or other parts of the cardiovascular system. Synthesis of vitamin D from the sun does not cause vitamin D toxicity, because vitamin D synthesis is tightly regulated and decreases if the body has abundant vitamin D.

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9.7: Sources of Vitamins

Vitamins in Food

Eating a variety of foods from all food groups is the best way to ensure you are getting all the micronutrients needed for a healthy diet. Each food group lends itself to specific vitamins and minerals (see Figure 8.4). Keep in mind that whole foods (e.g., fresh fruits and vegetables, whole grains, lean meats, and low-fat dairy foods such as milk and cheese) contain more vitamins and minerals than their processed counterparts. A whole baked potato contains more vitamin C, folate, and potassium than a potato that is cut, soaked, and fried to make a french fry.



Figure 8.4. Common vitamins and minerals found in each food group.

Effects of Processing on Vitamin Content in Foods

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

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

Table 1. Effects of Food Processing on Nutrient Retention and Strategies to Minimize Nutrient Loss

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

Air exposure and time	Enzymes present in foods and exposure to air can destroy vitamins, because as soon as the food is harvested, the food begins to slowly decompose.	Purchase fresh items in quantities that can be used as soon as possible. Cut up foods only when ready to use. Buy local produce to cut back on transport time and air exposure.
Temperature	Cooking helps kill bacteria, makes foods more appealing, and in some situations improves bioavailability of nutrients. But high temperatures for prolonged amounts of time can destroy some vitamins.	Use fast cooking methods like microwaving, steaming, or stir-frying.
Water	Minerals and water-soluble vitamins can leach into the water.	Don't soak produce in water. Limit the amount of water used to cook foods (e.g., steam vegetables rather than boil them). Use cooking water in food preparation.
Canning	High temperatures may be used, which can destroy water-soluble vitamins, but commercial techniques usually use rapid heating, which helps to reduce nutrient loss.	Choose a variety of canned goods that don't have added sugars or sodium to maximize nutrient density.
Freezing	Freezing does not reduce nutrient content, but if foods are blanched prior to freezing it may slightly reduce levels of water-soluble vitamins.	Choose a variety of frozen goods that don't have added sugars, syrups, or sauces to maximize nutrient density.
Refining of grains	Many B vitamins, minerals, and phytochemicals, as well as fiber, are lost when whole grains are refined.	Choose whole grains whenever possible.

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

Fortified Foods

Food fortification is a public health strategy where essential vitamins and minerals — such as iron, folic acid, B vitamins, vitamin A, zinc, and iodine — are deliberately added to commonly consumed staple foods to improve nutrition and prevent micronutrient deficiencies. The Food Fortification Initiative (FFI) plays a critical role in this global effort, focusing specifically on the fortification of industrially milled wheat flour, maize flour, and rice. In the U.S., fortification is well established — wheat flour and many grain products are enriched with iron, folic acid, thiamin, riboflavin, and niacin.

A significant public health milestone came in 1998 when regulations mandated adding folic acid to grain products, such as flour, rice, pasta, and bread to reduce neural tube defects. Mandatory fortification with folic acid has had measurable success: Neural tube defects dropped by roughly 35%, preventing an estimated 1,300 affected births annually.

Iodized salt, another staple, remains one of the simplest yet most widespread fortification efforts to address iodine deficiency. FFI also points out that while wheat, maize, and rice are fortified as part of national standards in the U.S., corn masa products currently lag behind — with less than 6 % fortified — highlighting opportunities for further nutritional improvement.

Table 2. Overview of U.S. Food Fortification Policies and Requirements

Policy Area	Status	Requirements
Enriched Grains	Voluntary use with standards	If labeled "enriched," must meet FDA nutrient levels (B-vitamins, iron, folic acid)
Folic Acid in Grains	Mandatory (since 1998)	Required in enriched grain products to prevent neural tube defects
Vitamin D in Milk	Optional standard	Milk may be fortified with vitamins A & D
Iodized Salt	Voluntary	Nationally common; labeling regulated
Fortification of Other Foods	Voluntary & regulated via policy	Based on sound public health rationale, but no mandate

Vitamin Synthesis in the Body

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

Vitamins Made From Precursors

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



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

needed for protein synthesis. The efficiency in which tryptophan is converted to niacin varies greatly in individuals.[4]

Vitamins Made by Intestinal Bacteria

Some vitamins can be synthesized not by our bodies, but by the helpful bacteria A yogurt parfait with granola and fresh berries in a clear glass is shown sitting on a table living within us. **Bacteria in the gut can make vitamin K and B vitamins.**

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

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9.8: Dietary Supplements

By now you know that a balanced, nutritious diet is important for good health. But you may also wonder if your diet is adequate, or if you could benefit from taking a vitamin or mineral supplement. You may also be curious about other supplements that claim to help you lose weight, build muscle, ease joint pain, or help build good bacteria in your gut.



According to the results of a large national survey published in JAMA in 2016, 52% of U.S. adults reported using supplements in 2011-2012.[2] With over half of Americans reporting dietary supplement use, it's important to have a conversation about the safety and efficacy of these products. Are dietary supplements safe? Are they effective? Do Americans need a multivitamin/mineral supplement? If so, what are the guidelines and recommendations for choosing a supplement? We will explore these important questions in this section.

Regulation of Dietary Supplements

A ***dietary supplement*** is defined as a product that:[1]

- is intended to supplement the diet
- contains one or more dietary ingredients (e.g., vitamins, minerals, herbs or other botanicals, amino acids, and enzymes)
- can be taken by mouth as a pill, capsule, tablet, or liquid
- is labeled as being a dietary supplement

The Food and Drug Administration (FDA) regulates dietary supplements, but under a different set of regulations than foods, pharmaceuticals, and over-the-counter drugs. In 1994, the Dietary Supplement Health and Education Act (DSHEA) created new regulations for the labeling and safety of dietary supplements. Under these rules, the **"FDA is not authorized to review dietary supplement products for safety and effectiveness before they are marketed**."[3] Therefore, the responsibility falls on the manufacturers and distributors of dietary supplements to ensure their products are safe before they go to consumers. **The FDA has to prove that the product is unsafe in order to remove it from the market.** This is a big contrast from pharmaceuticals, which must obtain approval from the FDA, showing substantial evidence that their drugs are safe and effective before reaching the marketplace.

The FDA issued Good Manufacturing Practices (GMPs) for dietary supplements in 2007. GMPs are a set of requirements and expectations by which dietary supplements must be manufactured, prepared, and stored to ensure quality.[4] Manufacturers are expected to guarantee the identity, purity, strength, and composition of their dietary supplements.[4]

Once a dietary supplement is on the market, the FDA tracks side effects reported by consumers, supplement companies, and others. If the FDA finds a product to be unsafe, it can take legal action against the manufacturer or distributor and may issue a warning or require that the product be removed from the marketplace. However, the FDA says it can't test all products marketed as dietary supplements that may have potentially harmful hidden ingredients.

Safety of Dietary Supplements

With current regulations, the safety of dietary supplements is the manufacturers' responsibility. Unfortunately, manufacturers don't always have the public's best interest in mind, especially when there is a profit to be gained.



According to the FDA website, the "FDA has found that manufacturing problems have been associated with dietary supplements. Products have been recalled because of microbiological, pesticide, and heavy metal contamination and because they do not contain the dietary ingredients they are represented to contain or they contain more or less than the amount of the dietary ingredient claimed on the label."[2]

What this means for consumers is that they should use caution when considering whether to use a dietary supplement. Keep in mind the following information from the Center for Complementary and Integrative Health at the National Institutes of Health:[1]

- **What's on the label may not be what is in the product.** For example, the FDA has found prescription drugs, including anticoagulants (e.g., warfarin), anticonvulsants (e.g., phenytoin), and others, in products being sold as dietary supplements. You can see a list of some of those products on the FDA's Tainted Supplements webpage.
- **Supplement labels may make illegal claims** to make their product more appealing. A 2012 Government study of 127 dietary supplements marketed for weight loss or to support the immune system found that 20 percent made illegal claims.
- **Dietary supplements can interact with other medications, and cause harm**. For example, the herbal supplement St. John's wort makes many medications less effective.
- **The term natural does not always mean safe.** Ephedra, an evergreen plant native to central Asia is associated with heart problems and risk of death. In 2004, the FDA banned the sale of ephedrine in dietary supplements for these reasons. Supplements can contain natural herbs and other plant-based ingredients that have not been adequately studied. We don't know if supplement ingredients are dangerous until people end up really sick or even die from them. Dietary supplements result in an estimated 23,000 emergency room visits every year in the United States, according to a 2015 study. Many of the patients are young adults having heart problems from weight-loss or energy products and older adults having swallowing problems from taking large vitamin pills.
- **The term"standardized" (or "verified" or "certified") on a supplement does not always guarantee product quality or safety.** These are terms used by manufacturers to sell their product and have not been legally defined.

You can report safety concerns about a dietary supplement through the U.S. Health and Human Services Safety Reporting Portal. For more information on contaminants in dietary supplements, visit the FDA's Dietary Supplement Products & Ingredients

webpage.

Efficacy of Dietary Supplements

The amount of scientific evidence on dietary supplements varies widely—there is a lot of information on some and very little on others. The Center for Complementary and Integrative Health at the National Institutes of Health offers these key points about efficacy of dietary supplements:[1]

- Dietary supplements can't be marketed with claims that they can diagnose, treat, cure, mitigate, or prevent any disease; such claims would require the product to be approved by the FDA as a pharmaceutical. Instead, dietary supplements are marketed with health claims or structure/function claims, similar to claims on food labels. Recall from Unit 1 that structure/function claims (e.g., "builds strong bones," or "boosts immunity") are intentionally vague and require no evidence to support them. Supplements are often labeled with claims that have little to no scientific basis.
- Studies have found that some dietary supplements may have benefits, such as melatonin for jet lag. Others may have little or no benefit, such as ginkgo for dementia.[1] Many dietary supplements haven't been studied at all in humans.
- Studies of many supplements haven't supported claims made about them. For example, in several studies, echinacea didn't help cure colds and Ginkgo biloba wasn't useful for dementia—but you can still find Ginkgo biloba supplements with claims that they improve memory and echinacea supplements with claims of providing "immune support." Many times the research on a dietary supplement is conflicting, such as whether the supplements glucosamine and chondroitin improve symptoms of osteoarthritis.[1] Research design and interpretation can also be biased when funded by the supplement industry.
- Most research shows that taking multivitamin/mineral (MVM) supplements doesn't result in living longer, slowing cognitive decline, or lowering the chance of getting cancer, heart disease, or diabetes. However, taking a multivitamin is unlikely to pose health risks, providing you follow the guidelines below for choosing supplements.[1]

Guidelines for Choosing Supplements

Throughout this text, we have discussed the importance of whole foods. As you might suspect, supplements can not replace real, whole food. Marion Nestle, professor emerita at New York University and author of many books about nutrition, wrote eloquently about the benefits of getting nutrients from food instead of supplements in a 2006 blog post:

> *" Unless you have been diagnosed with a vitamin or mineral deficiency and need to replenish that nutrient in a great big hurry, it is always better to get nutrients from foods—the way nature intended. I can think of three benefits of whole foods as compared to supplements:*
>
> *(1) you get the full variety of nutrients—vitamins, minerals, antioxidants, etc–in that food, not just the one nutrient in the supplement;*
>
> *(2) the amounts of the various nutrients are balanced so they don't interfere with each other's digestion, absorption, or metabolism; and*
>
> *(3) there is no possibility of harm from taking nutrients from foods (OK. Polar bear liver is an exception; its level of vitamin A is toxic).*
>
> *In contrast, high doses of single nutrients not only fail to improve health but also can make things worse, as has been shown in some clinical trials of the effects of beta-carotene, vitamin E, and folic acid, for example, on heart disease or cancer. And foods taste a whole lot better, of course. "* [5]

However, there are certain populations that might be at risk for developing nutrient deficiencies, and they may benefit from a MVM supplement or supplements of specific nutrients. These groups include the elderly, strict vegetarians or vegans, people restricting their caloric intake, pregnant women, or individuals with food insecurity.[6]

If you choose to take supplements, keep moderation in mind, and use the following guidelines to help you choose a supplement.

1. **Don't substitute for whole foods.** According to the 2015 Dietary Guidelines for Americans, "Nutritional needs should be met primarily from foods. Individuals should aim to meet their nutrient needs through healthy eating patterns that include nutrient-dense foods." Whole foods are complex and not only contain essential vitamins and minerals, but also dietary fiber and

phytochemicals that may have positive health benefits. Supplements should never act as a replacement for whole food, but rather a supplement to fill in some nutritional gaps.

2. **Check the dose carefully.** Since dietary supplements are not regulated before they hit the market, it is not uncommon to find nutrient levels that exceed the upper intake level (UL). A good rule-of-thumb is to choose a supplement that keeps the dose close to 100% of the Daily Value (unless advised by a doctor to help correct a deficiency) and definitely no more than the UL.

3. **If getting supplements from multiple sources, make sure you add together the doses**. Supplements not only come in pill form, but also powder and liquid form. Vitamin water, protein powder, and other products like Emergen-C are often fortified with large amounts of vitamins and minerals.

4. **Be skeptical of product claims.** Remember that supplement manufacturers promote their products with structure/function claims, and they don't have to provide any evidence that the product actually does what it claims to do. If something sounds too good to be true, it probably is.

5. **Look for third-party testing when purchasing a supplement.** ConsumerLab.com, NSF International, U.S. Pharmacopeia (USP), and UL are all companies that do third-party testing on dietary supplements.[7] If you see these companies' stamps (see Figure 8.5) on a supplement bottle, it means that the product is periodically tested to check that it:

- Contains the ingredients listed on the label, in the declared potency and amounts.
- Does not contain harmful levels of specified contaminants (e.g., heavy metals and pesticides).
- Will break down and release into the body within a specified amount of time. (If a supplement does not break down properly to allow its ingredients to be available for absorption in the body, the consumer will not get the full benefit of its contents.)



Figure 8.5. The U.S. Pharmacopeia (USP) verification mark. USP is a nonprofit organization that does third-party testing on dietary supplements. This mark helps assure consumers that the product has been tested for quality, purity, potency, performance, and consistency.[8]

6. **Choose a MVM supplement that is tailored to your age, sex, and other characteristics (e.g., pregnacy).** This is important because different populations have different nutrient needs. MVMs for seniors typically provide more calcium and vitamin D for bone health than MVMs for younger adults. MVMs for women contain more iron than MVMs for men. Prenatal supplements generally provide no vitamin A as retinol, and most children's MVMs provide age-appropriate amounts of nutrients.[10]

7. **Check with your healthcare provider to ensure the supplement you are considering is safe for you.** Supplements can interact with both prescription medications and over-the-counter medications potentially causing life-threatening complications.

VIDEO: "Supplements and Safety" by Frontline, PBS.org (January 19, 2016), 54:11 minutes. "An investigation into the hidden dangers of vitamins and supplements, a multibillion-dollar industry with limited FDA oversight. FRONTLINE, The New York Times and the Canadian Broadcasting Corporation examine the marketing and regulation of supplements, and cases of contamination

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9.9: Phytochemicals

Although not presently considered essential nutrients, phytochemicals are chemicals in plant-source foods that potentially provide some health benefits. Carotenoids are one type of phytochemical. Phytochemicals also include indoles, lignans, phytoestrogens, stanols, saponins, terpenes, flavonoids, carotenoids, anthocyanidins, phenolic acids, and many more. They are found not only in fruits and vegetables, but also in grains, seeds, nuts, and legumes.

Many phytochemicals act as antioxidants, but they have several other functions, such as mimicking hormones, altering absorption of cholesterol, inhibiting inflammatory responses, and blocking the actions of certain enzymes.

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

Table 9.9.1: Some Phytochemical's Obtained from Diet and Their Related Functions

Phytochemical	Phytochemical Source	Phytochemical Function:
Carotenoid	Yellow-orange fruits, dark green leafy vegetables	May possess strong cancer-fighting properties
Indoles	Cruciferous vegetables (i.e. bok choy, broccoli, choy sum)	May inhibit the development of cancer-causing hormones and prevent tumor growth
Phytoestrogen	Grapes, berries, plums, soybeans, tofu, garlic	May lower the risk for osteoporosis, heart disease, breast cancer, and menopausal symptoms
Stanols	Grains, nuts, legumes	May lower blood cholesterol levels and reduce the risk of heart disease and stroke
Saponins	Broad beans, kidney beans, lentils	May decrease blood lipids, lower cancer risks, and lower blood glucose response
Terpenes	Citrus fruits	May slow cancer cell growth, aid in immune system support, and prevent virus related illness
Flavonoids	Fruits, vegetables, chocolates, wines, teas, nuts, seeds	May benefit the immune system and prevent cancer cell growth.
Anthocyanidins	Fruits and vegetables with vibrant colors of orange, red, purple, and blue	May prevent cardiovascular disease, reduce cancer cell proliferation (growth/multiplication) and inhibit tumor formation.
Phenolic acids	Coffee, fruits, vegetables, nuts, cereals, legumes, oilseeds, beverages and herbs	May prevent cellular damage due to free-radical oxidation reaction and promote anti-inflammatory conditions in the body.

Query 9.9.1

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CHAPTER 10: WATER AND MINERALS

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10.1: Water

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10.1.1: Water's Importance to Vitality

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



Figure 10.1.1.1: Image by NASA on unsplash.com / CC0

Water is the foundation of all life—the surface of the earth is 70 percent water; the volume of water in humans is about 60 percent.

Water As a Transportation Vehicle

Water is called the "universal solvent" because more substances dissolve in it than any other fluid. Molecules dissolve in water because of the hydrogen and oxygen molecules ability to loosely bond with other molecules. Molecules of water (H_2O) surround substances, suspending them in a sea of water molecules. The solvent action of water allows for substances to be more readily transported. A pile of undissolved salt would be difficult to move throughout tissues, as would a bubble of gas or a glob of fat. Blood, the primary transport fluid in the body is about 78 percent water. Dissolved substances in blood include proteins, lipoproteins, glucose, electrolytes, and metabolic waste products, such as carbon dioxide and urea. These substances are either dissolved in the watery surrounding of blood to be transported to cells to support basic functions or are removed from cells to prevent waste build-up and toxicity. Blood is not just the primary vehicle of transport in the body, but also as a fluid tissue blood structurally supports blood vessels that would collapse in its absence. For example, the brain which consists of 75 percent water is used to provide structure.

Water As a Medium for Chemical Reactions

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

Water As a Lubricant/Shock Absorber

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

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

Water As a Temperature Regulator

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

There are several mechanisms in place that move body water from place to place as a method to distribute heat in the body and equalize body temperature (Figure 10.1.1.2). The hypothalamus in the brain is the thermoregulatory center. The hypothalamus contains special protein sensors that detect blood temperature. The skin also contains temperature sensors that respond quickly to changes in immediate surroundings. In response to cold sensors in the skin, a neural signal is sent to the hypothalamus, which then sends a signal to smooth muscle tissue surrounding blood vessels causing them to constrict and reduce blood flow. This reduces heat lost to the environment. The hypothalamus also sends signals to muscles to erect hairs and shiver and to endocrine glands like the thyroid to secrete hormones capable of ramping up metabolism. These actions increase heat conservation and stimulate its production in the body in response to cooling temperatures.

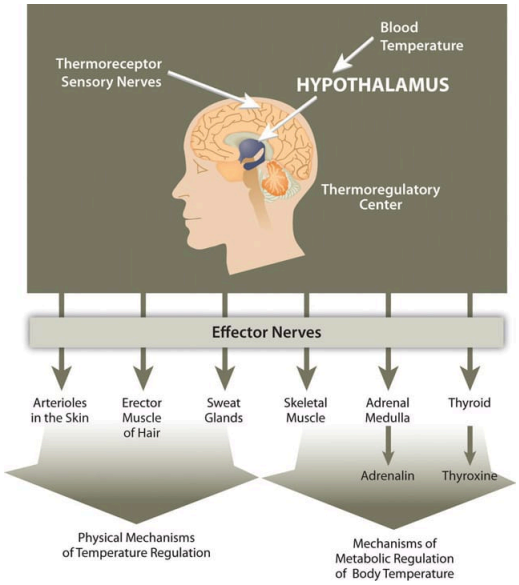


Figure 10.1.1.2: Thermoregulatory Center. Thermoregulation is the ability of an organism to maintain body temperature despite changing environmental temperatures.

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10.1.2: Regulation of Water Balance

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

Regulation of Daily Water Input

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

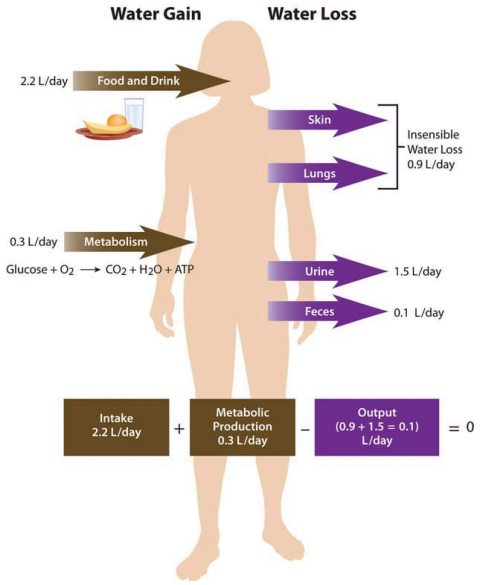


Figure 10.1.2.1: Daily Fluid Loss and Gain. CO2 + H20 + ATP); sources of water loss: Skin and lungs (insensible water loss 0.9 L/day), Urine 1.5 L/day, Feces 0.1 L/day. TOTAL intake 2.2 L/day + Metabolic Production 0.3 L/day – Output (0.9+1.5=0.1) L/day = 0 " class="wp-image-141 size-full" width="629" height="777"> Daily Fluid Loss and Gain

Dietary Recommendations

The Food and Nutrition Board of the Institute of Medicine (IOM) has set the Adequate Intake (AI) for water for adult males at 3.7 liters (15.6 cups) and at 2.7 liters (11 cups) for adult females.[1] These intakes are higher than the average intake of 2.2 liters. It is important to note that the AI for water includes water from all dietary sources; that is, water coming from food as well as beverages. People are not expected to consume 15.6 or 11 cups of pure water per day. In America, approximately 20 percent of dietary water comes from solid foods. See Table 10.1.2.1 for the range of water contents for selected food items. Beverages includes water, tea, coffee, sodas, and juices.

Table 10.1.2.1: Water Content in Foods

Percentage	Food Item
90–99	Nonfat milk, cantaloupe, strawberries, watermelon, lettuce, cabbage, celery, spinach, squash
80–89	Fruit juice, yogurt, apples, grapes, oranges, carrots, broccoli, pears, pineapple
70–79	Bananas, avocados, cottage cheese, ricotta cheese, baked potato, shrimp

Percentage	Food Item
60–69	Pasta, legumes, salmon, chicken breast
50–59	Ground beef, hot dogs, steak, feta cheese
40–49	Pizza
30–39	Cheddar cheese, bagels, bread
20–29	Pepperoni, cake, biscuits
10–19	Butter, margarine, raisins
1–9	Walnuts, dry-roasted peanuts, crackers, cereals, pretzels, peanut butter
0	Oils, sugars

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

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

Thirst Mechanism: Why Do We Drink?

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

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

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

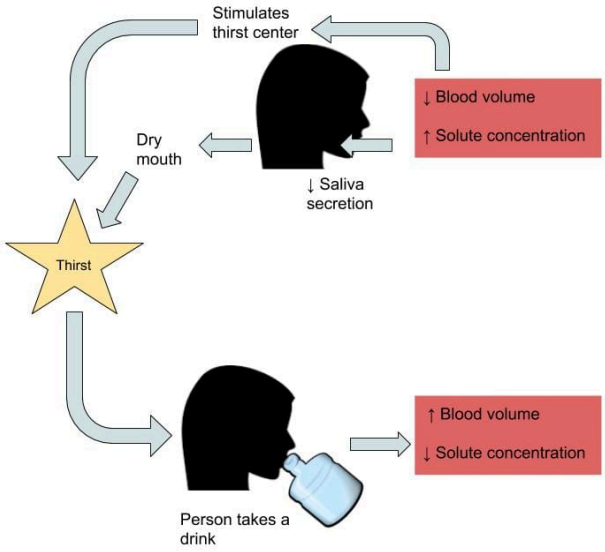


Figure 10.1.2.2: Regulating Water Intake. Image by Allison Calabrese / CC BY 4.0

Regulation of Daily Water Output

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

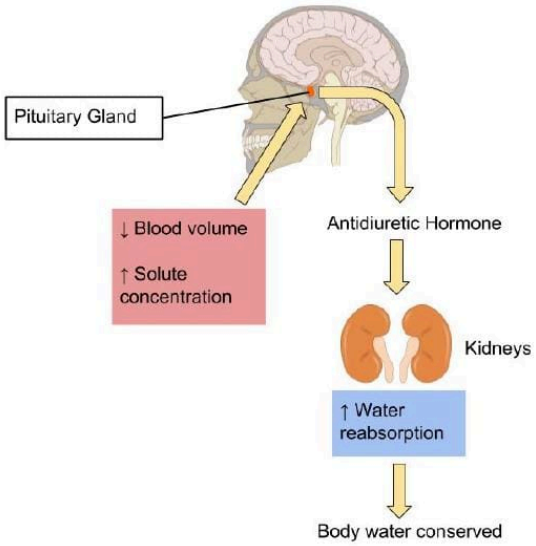


Figure 10.1.2.3: Regulating Water Output. Image by Allison Calabrese / CC BY 4.0

The Kidneys Detect Blood Volume

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

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

The Hypothalamus Detects Blood Osmolality

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

The Adrenal Glands Detect Blood Osmolality

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

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10.1.3: Water Concerns

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

Reading the Label

Most beverages marketed in the United States have a Nutrition Facts panel and ingredients list, but some, such as coffee (for home consumption), beer, and wine, do not. As with foods, beverages that are nutrient-dense are the better choices, with the exception of plain water, which contains few to no other nutrients. Beverages do not make you full; they satiate your thirst. Therefore, the fewer calories in a beverage the better it is for avoiding weight gain. For an estimate of kilocalories in various beverages see Table 10.1.3.1.

Table 10.1.3.1*: Calories in Various Beverages*

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

Beverage Consumption in the United States

According to the Beverage Marketing Corporation, in the United States in 2010 Americans consumed 29,325 millions of gallons of refreshment beverages including soft drinks, coffee, tea, sports drinks, energy drinks, fruit drinks, and bottled water.[1]

As in the past, carbonated soft drinks remained the largest category of consumed beverages. In recent decades total caloric consumption has increased in the United States and is largely attributed to increased consumption of snacks and caloric beverages. People between the ages of nineteen and thirty-nine obtain 10 percent of their total energy intake from soft drinks.[2]

In all age groups the consumption of total beverages provides, on average, 21 percent of daily caloric intake. This is 7 percent higher than the IOM acceptable caloric intake from beverages. Moreover, the high intakes of soft drinks and sugary beverages displace the intake of more nutrient-dense beverages, such as low-fat milk.

Scientific studies have demonstrated that while all beverages are capable of satisfying thirst they do not make you feel full, or satiated. This means that drinking a calorie-containing beverage with a meal only provides more calories, as it won't be offset by

eating less food. The Beverage Panel of the University of North Carolina, Chapel Hill has taken on the challenge of scientifically evaluating the health benefits and risks of beverage groups and providing recommendations for beverage groups (Table 10.1.3.2). In regards to soft drinks and fruit drinks, The Beverage Panel states that they increase energy intake, are not satiating, and that there is little if any reduction in other foods to compensate for the excess calories. All of these factors contribute to increased energy intake and obesity.[3]

The Beverage Panel recommends an even lower intake of calories from beverages than IOM—10 percent or less of total caloric intake.

Table 10.1.3.2: Recommendations of the Beverage Panel

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

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

Sources of Drinking Water

The Beverage Panel recommends that women drink at least 32 ounces and men drink at least 48 ounces of water daily. In 1974, the US federal government enacted The Safe Drinking Water Act with the intention of providing the American public with safe drinking water. This act requires the Environmental Protection Agency (EPA) to set water-quality standards and assure that the 150,000-plus public water systems in the country adhere to the standards. About 15 percent of Americans obtain drinking water from private wells, which are not subject to EPA standards. Producing water safe for drinking involves some or all of the following processes: screening out large objects, removing excess calcium carbonate from hard water sources, flocculation, which adds a precipitating agent to remove solid particles, clarification, sedimentation, filtration, and disinfection. These processes aim to remove unhealthy substances and produce high-quality, colorless, odorless, good-tasting water. Most drinking water is disinfected by the process of chlorination, which involves adding chlorine compounds to the water. Chlorination is cheap and effective at killing bacteria. However, it is less effective at removing protozoa, such as Giardia lamblia. Chlorine-resistant protozoa and viruses are instead removed by extensive filtration methods. In the decades immediately following the implementation of water chlorination and disinfection methods in this country, waterborne illnesses, such as cholera and typhoid fever, essentially disappeared in the United States (Figure 10.1.3.1). In fact, the treatment of drinking water is touted as one of the top public-health achievements of the last century.

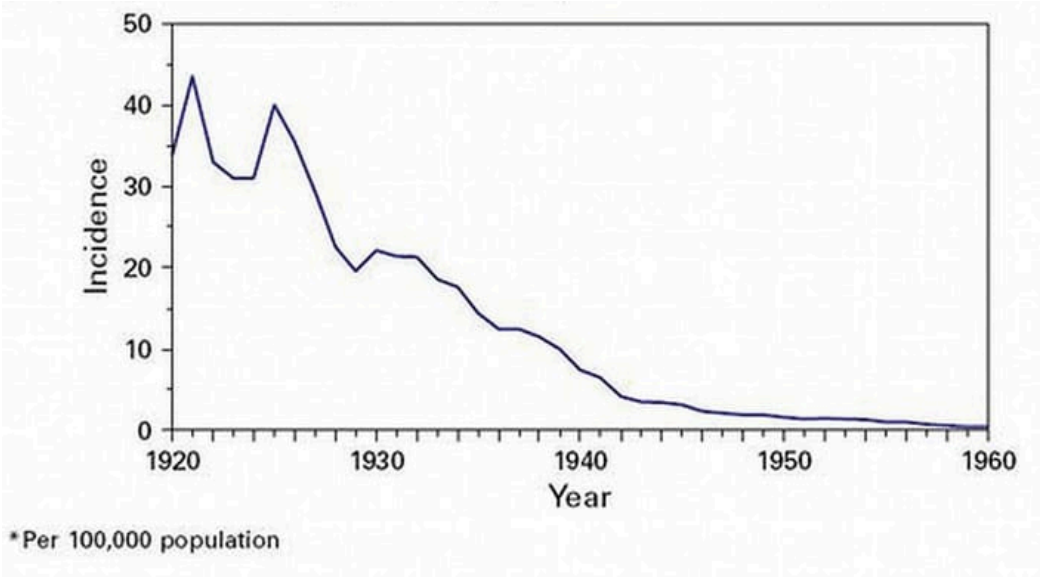


Figure 10.1.3.1: Deadly Water-borne Illnesses In United States. Deadly water-borne illnesses decreased to almost nonexistent levels in the United States after the implementation of water disinfection methods. Source: Image credit Robert Tauxe. Drinking Water Week. Centers for Disease Control and Prevention. http://www.cdc.gov/features/drinkingwater/graph.html. Updated May 17, 2012. Aceessed September 22, 2017.

Chlorine reaction with inadequately filtered water can result in the formation of potentially harmful substances. Some of these chlorinated compounds, when present at extremely high levels, have been shown to cause cancer in studies conducted in rodents. In addition to many other contaminants, the EPA has set maximum contaminant levels (legal threshold limits) for these chlorinated compounds in water, in order to guard against disease risk. The oversight of public water systems in this country is not perfect and water-borne illnesses are significantly underreported; however, there are far fewer cases of water-borne illnesses than those attributed to food-borne illnesses that have occurred in the recent past.

Bottled water vs. tap water

When choosing drinking water, many people are faced with the decision between bottled and tap water. While both are widely available and generally safe to drink in many countries, especially in the United States, there are significant differences in their regulation, cost, environmental impact, and nutrient content that are important to understand.

Tap Water: Heavily Regulated, Safe, and Beneficial

Tap water in the United States is regulated by the Environmental Protection Agency (EPA) under the Safe Drinking Water Act. This legislation requires water utilities to regularly test for over 90 contaminants and meet strict safety standards to ensure that the water is safe for public consumption (U.S. EPA, 2023). In many municipalities, tap water is treated and monitored more frequently than bottled water, which is regulated by the Food and Drug Administration (FDA) and held to slightly different — and often less stringent — standards.

In addition to safety, municipal tap water is commonly fluoridated, meaning a small amount of fluoride is added to promote dental health. This public health intervention has been endorsed by major health organizations including the Centers for Disease Control and Prevention (CDC), which has called community water fluoridation one of the ten great public health achievements of the 20th century (CDC, 2020). Fluoride plays a key role in strengthening tooth enamel and preventing cavities. Its function in human nutrition, particularly in bone and dental health, will be explored further in this textbook in the section on *Minerals and Bone Health*.

Bottled Water: Convenience at a Cost

While bottled water is often perceived as cleaner or safer than tap water, this perception is not always supported by evidence. In fact, some bottled water products are simply repackaged municipal tap water, often without any additional treatment. Unlike municipal tap water, bottled water is not required to disclose its source or treatment process on the label, and oversight of bottled water quality is less frequent and comprehensive than for public water supplies (NRDC, 2019).

Another concern with bottled water, particularly when sold in single-use plastic bottles, is its environmental impact. Plastic bottles contribute significantly to plastic waste, much of which ends up in landfills or the environment. In 2022, only about 5–6% of plastic in the U.S. was recycled (EPA, 2023), and bottled water is a major contributor to the global plastic pollution problem.

Furthermore, studies have found microplastics — tiny plastic particles — in many bottled water samples. A 2018 study conducted by researchers at the State University of New York found that over 90% of bottled water brands tested contained microplastics, raising questions about long-term exposure through consumption (Mason et al., 2018).

Choosing Tap Water

For most people in communities with regulated municipal water systems, tap water offers a safe, affordable, and environmentally responsible option. It typically costs a fraction of a cent per gallon, provides a reliable source of fluoride for dental health, and avoids the environmental drawbacks associated with disposable plastic bottles.

While bottled water can be useful in certain circumstances — such as in areas without safe tap water or during emergencies — the routine use of bottled water is generally not necessary and may carry hidden costs both to the consumer and to the environment.

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1. US Liquid Refreshment Beverage Market Increased by 1.2% in 2010, Beverage Marketing Corporation Reports. Beverage Marketing Corporation. http://www.beveragemarketing.com/?section=pressreleases. Published 2010. Accessed March 17, 2011. ↩
2. Beverage Intake in the United States. The Beverage Panel, University of North Carolina, Chapel Hill. http://www.cpc.unc.edu/projects/beverage. Accessed October 2, 2011. (See Figure 6.8.) ↩
3. US Liquid Refreshment Beverage Market Increased by 1.2% in 2010, Beverage Marketing Corporation Reports.Beverage Marketing Corporation. http://www.beveragemarketing.com/?section=pressreleases. Accessed March 17, 2011. ↩
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10.1.4: Popular Beverage Choices

Caffeine-containing Beverages

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

Typical Doses and Dietary Sources

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

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

The average caffeine consumption for American adults is considered moderate at 280 milligrams per day, although it is not uncommon for people to consume up to 600 milligrams per day. This works out to almost 4 ½ cups of coffee per day. The bitter taste of caffeine is palatable for many and coffee is the most readily available source of it, accounting for 70 percent of daily caffeine consumption. The second readily available source of caffeine is soft drinks, delivering 16 percent of daily caffeine. (In this case, the bitter caffeine taste is usually masked by a large amount of added sugar.) Tea is the third common source of caffeine, at 12 percent.

Just how much caffeine is there in a cup of coffee? It varies. The caffeine content of an average cup of coffee can range from 102 to 200 milligrams, and the range for tea is 40 to 120 milligrams. Table 10.1.4.1 provides useful information on the levels of caffeine found in common beverages. When estimating your total caffeine consumption remember it's not only in beverages, but also some foods and medicine.

Table 10.1.4.1: Caffeine Content in Various Beverages and Foods

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

Beverage/Food	Milligrams
Monster Energy (16 oz.)	160
Spike Shooter (8.4 oz.)	300

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

Effects of Caffeine

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

Health Benefits

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

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



Figure 10.1.4.1: Photo by Jeremy Ricketts on unsplash.com / CC0

A growing body of epidemiological research indicates that regular moderate coffee consumption is associated with numerous health benefits, with only limited evidence of harm under typical usage. Meta-analyses of cohort studies show that each additional cup of coffee per day is associated with about a **3% lower overall cancer risk** compared to non- or low-consumption, with particularly consistent inverse associations for cancers of the liver (hepatocellular carcinoma), endometrium, colorectum, breast, prostate, oral/pharyngeal sites, and leukemia. (PubMed) For example, in one large prospective UK Biobank study, risk of hepatocellular carcinoma was about halved in coffee drinkers relative to non-drinkers, and this was roughly similar across instant and ground forms. (PubMed) The evidence is less clear (and sometimes null) for certain other cancers; importantly, much of the

apparent associations are stronger for moderate vs heavy consumption, and confounding factors (such as smoking or very hot beverage temperature) must be considered. (Health.gov)

With respect to cognitive function, systematic reviews and meta-analyses find that caffeine (especially from coffee or green tea) in moderate amounts (e.g. ~100-400 mg/day) is related to reduced risk of cognitive decline and dementia, and may slow decline in already cognitively impaired individuals. (PubMed) One meta-analysis suggests that about **2.5 cups of coffee/day** yields maximal protective effect for Alzheimer's disease risk. (PubMed)

Beyond cancer and cognition, newer work is exploring how coffee may promote healthy aging via effects on metabolism, inflammation, and cellular processes: there is evidence for reduced risk of type 2 diabetes, favorable cardiometabolic markers, lower mortality rates, improved liver health (lower cirrhosis risk, better liver enzyme profiles), and possible reduction in recurrence for some cancers. (MDPI) Mechanistic studies attribute many effects to the polyphenols, diterpenes (such as cafestol and kahweol), and other bioactive compounds in roasted coffee, which may exert antioxidant, anti-inflammatory, insulin-sensitizing, and even epigenetic or apoptotic influences. (MDPI)

There is also scientific evidence supporting that higher consumption of caffeine, mostly in the form of coffee, substantially reduces the risk for developing Parkinson's disease. There is a lesser amount of evidence suggesting increased coffee consumption lowers the risk of heart attacks in both men and women, and strokes in women. In smaller population studies, decaffeinated coffee sometimes performs as well as caffeinated coffee, bringing up the hypothesis that there are beneficial chemicals in coffee other than caffeine that play larger roles in the health benefits of coffee. A review of fifteen epidemiological studies in The Journal of the American Medical Association proposes that habitual coffee consumption reduces the risk of Type 2 diabetes.[1] The risk reduction was 35 percent for those who consumed greater than 6–7 cups of coffee per day and was 28 percent for those who consumed 4–5 cups daily. These groups were compared with people who consumed less than 2 cups of coffee per day.

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

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

Adverse Effects

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

Drinking beverages at very high temperatures (above 65°C), including hot coffee and tea, has been classified by the International Agency for Research on Cancer (IARC) as *probably carcinogenic to humans* due to evidence linking it to an increased risk of esophageal cancer (IARC Monograph Volume 116, 2016).

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

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

Caffeinated beverages are dehydrating — A myth?

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

However, at higher doses or in caffeine-naïve individuals, caffeine may elicit a stronger diuretic response. The renal effects of caffeine are mediated in part by adenosine receptor antagonism in the kidneys, which may blunt sodium reabsorption and influence glomerular dynamics. While some studies suggest potential alterations in glomerular filtration or sodium excretion, caffeine does not consistently increase renal blood flow or effective renal plasma flow in healthy individuals. In disease models or high-risk populations, chronic caffeine exposure has shown mixed effects on renal function.

Thus, caffeinated beverages are considered a source of hydration similar to water — moderate caffeine intake from beverages like coffee and tea is compatible with good hydration and does not significantly disrupt renal hemodynamics in healthy adults.

Sports Drinks

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

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

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

Who Needs Sports Drinks?

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

Sports Drink Alternatives

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

The Bottom Line

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

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10.2: Minerals Introduction and Overview — Major and Trace

Minerals

Similar to vitamins, minerals are micronutrients that are essential to human health and can be obtained in our diet from different types of food. Minerals are abundant in our everyday lives. From the soil in your front yard to the jewelry you wear on your body, we interact with minerals constantly. ***Minerals*** are inorganic elements in their simplest form, originating from the Earth. They can't be broken down or used as an energy source, but like vitamins, serve essential functions based on their individual characteristics. Living organisms can't make minerals, so the minerals our bodies need must come from the diet. Plants obtain minerals from the soil they grow in. Humans obtain minerals from eating plants, as well as indirectly from eating animal products (because the animal consumed minerals in the plants it ate). We also get minerals from the water we drink. The mineral content of soil and water varies from place to place, so the mineral composition of foods and water differs based on geographic location.[2]



Classification of Minerals

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

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

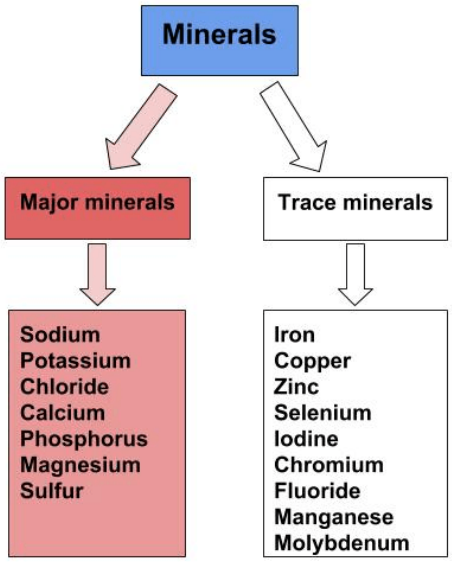


Figure 8.3. The classification of minerals as either major minerals or trace minerals.

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

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

- Minerals are generally better absorbed from animal-based foods. Plant-based foods often contain compounds that can bind to minerals and inhibit their absorption (e.g., oxalates, phytates).
- 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, mineral absorption can be impaired by certain gastrointestinal disorders and other diseases, such as Crohn's disease and kidney disease, as well as the aging process. Thus, people with malabsorption conditions and the elderly are at higher risk for mineral deficiencies.

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- Micronutrients Overview Kansas State University Human Nutrition CC BY 3.0

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- [1]Carpenter, K. J. (2003). A short history of nutritional science: part 3 (1912–1944). The Journal of nutrition, 133(10), 3023-3032.
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10.2.1: Summary of Major Minerals

Table 10.2.1.1*: A Summary of the Major Minerals*

Micronutrient	Sources	Recommended Intakes for adults	Major functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
Calcium	Yogurt, cheese, sardines, milk, orange juice, turnip	1,000 mg/day	Component of mineralized bone, provides structure and microarchitecture	Increased risk of osteoporosis	Postmenopausal women, those who are actoseintolerant, or vegan	Kidney stones	2,500 mg
Phosphorus	Salmon, yogurt, turkey, chicken, beef, lentils	700 mg/day	Structural component of bones, cell membrane, DNA and RNA, and ATP	Bone loss, weak bones	Older adults, alcoholics	None	3,000 mg
Magnesium	Whole grains and legumes, almonds, cashews, hazelnuts, beets, collards, and kelp	420 mg/day	Component of mineralized bone, ATP synthesis and utilization, carbohydrate, lipid,protein, RNA, and DNA synthesis	Tremor, muscle spasms, loss of appetite, nausea	Alcoholics, individuals with kidney and gastrointestinal disease	Nausea, vomiting, low blood pressure	350 mg/ day
Sulfur	Protein foods	None specified	Structure of some vitamins and amino acids, acid-base balance	None when protein needs are met	None	None	ND
Sodium	Processed foods, table salt, pork, chicken	< 2,300 mg/ day; ideally 1,500 mg/day	Major positive extracellular ion, nerve transmission, muscle contraction, fluid balance	Muscle cramps	People consuming too much water, excessive sweating, those with vomiting or diarrhea	High blood pressure	2,300 mg/ day
Potassium	Fruits, vegetables, legumes, whole grains, milk	Varies, depending on the person. See 2019 updated AIs here	Major positive intracellular ion, nerve transmission, muscle contraction, fluid balance	Irregular heartbeat, muscle cramps	People consuming diets high in processed meats, those with vomiting or diarrhea	Abnormal heartbeat	ND
Chloride	Table salt, processed foods	<3600 mg/day; ideally 2300 mg/day	Major negative extracellular ion, fluid balance	Unlikely	none	None	3,600 mg/ day

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10.2.2: Summary of Trace Minerals

Table 10.2.2.1: *Summary of the Trace Minerals*

Micronutrient	Sources	Recommended Intakes for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
Iron	Red meat, egg yolks, dark leafy vegetables, dried fruit, iron-fortified foods	8-18 mg/day	Assists in energy production, DNA synthesis required for red blood cell function	Anemia: fatigue, paleness, faster heart rate	Infants and preschool children, adolescents, women, pregnant women, athletes, vegetarians	Liver damage, increased risk of diabetes and cancer	45 mg/day
Copper	Nuts, seeds, whole grains, seafood	900 mcg/day	Assists in energy production, iron metabolism	Anemia: fatigue, paleness, faster heart rate	Those who consume excessive zinc supplements	Vomiting, abdominal pain, diarrhea, liver damage	10 mg/day
Zinc	Oysters, wheat germ, pumpkin seeds, squash,, beans, sesame seeds, tahini, beef, lamb	8-11 mg/day	Assists in energy production, protein, RNA and DNA synthesis; required for hemoglobinsynthesis	Growth retardation in children, hair loss, diarrhea, skin sores, loss of appetite, weight loss	Vegetarians, older adults	Depressed immune function	40 mg/day
Selenium	Meat, seafood, eggs, nuts	55 mcg/day	Essential for thyroid hormone activity	Fatigue, muscle pain, weakness, Keshan disease	Populations where the soil is low in selenium	Nausea, diarrhea, vomiting, fatigue	400 mcg/day
Iodine	Iodized salt, seaweed, dairy products	150 mcg/day	Making thyroid hormone, metabolism, growth and development	Goiter, cretinism, other signs and symptoms include fatigue, depression, weight gain, itchy skin, low heart-rate	Populations where the soil is low in iodine, and iodized salt is not used	Enlarged thyroid	1110 mcg/day
Chromium	Meats, nuts and whole grain	25-35 mcg/day	Assists insulin in carbohydrate, lipid and protein metabolism	abnormal glucose metabolism	Malnourished children	None	ND

Micronutrient	Sources	Recommended Intakes for adults	Major Functions	Deficiency diseases and symptoms	Groups at risk for deficiency	Toxicity	UL
Fluoride	Fluoridated water, foods prepared in fluoridated water, seafood	3-4 mg/day	Component of mineralized bone, provides structure and microarchitecture, stimulates new bone growth	Increased risk of dental caries	Populations with non fluoridated water	Fluorosismottled teeth, kidneydamage	10 mg/day
Manganese	Legumes, nuts, leafy green vegetables	1.8-2.3 mg/day	Glucose synthesis, amino-acid catabolism	Impaired growth, skeletal abnormalities, abnormal glucose metabolism	None	Nerve damage	11 mg/day
Molybdenum	Milk, grains, legumes	45 mcg/day	Cofactor for a number of enzymes	Unknown	None	Arthritis, joint inflammation	2 mg/day

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10.3: Minerals Involved In Fluid And Electrolyte Balance — Na, K, Cl

Water is the foundation of all life. The surface of the earth is 70% water, and human beings are mostly water, ranging from about 75% of body mass in infants, 50–60% in adults, and as low as 45% in old age. (The percent of body water changes with development, because the proportions of muscle, fat, bone, and other tissues change from infancy to adulthood.) Of all the nutrients, water is the most critical, as its absence proves lethal within a few days. The importance 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.

Maintaining the right level of water in your body is crucial to survival, as either too little or too much will result in less-than-optimal functioning. Several minerals are key to regulating water balance in different compartments of the body; the most important of these are sodium, potassium, and chloride.

Water Distribution and Composition

In the human body, water is distributed into two compartments: inside cells, called ***intracellular fluid (ICF)***, and outside cells, called ***extracellular fluid (ECF)***. Extracellular fluid includes both the fluid component of the blood (called ***plasma***) and the ***interstitial fluid*** **(IF)** that surrounds all cells not in the blood (Figure 8.6).

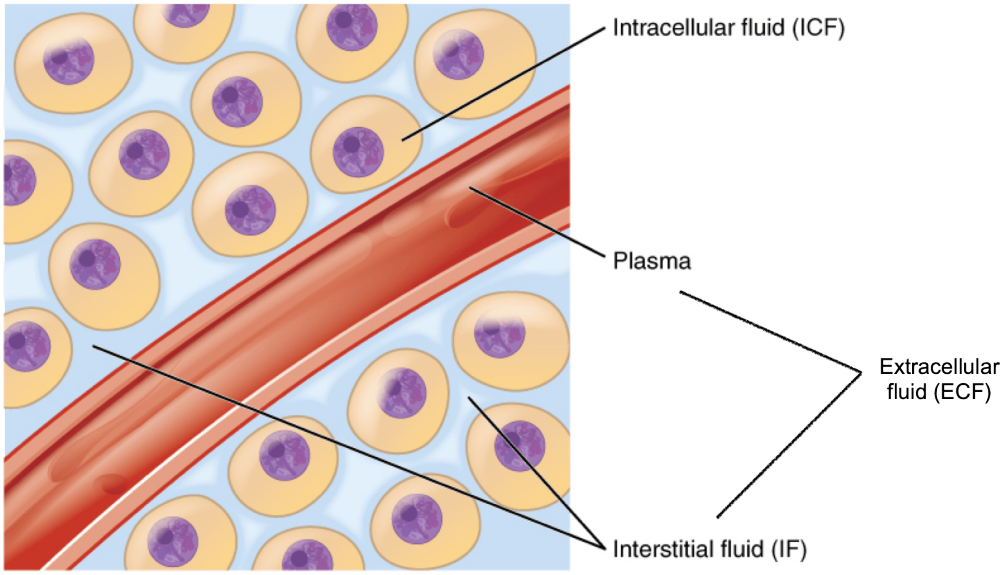


Figure 8.6. *Fluid compartments in the human body. The intracellular fluid (ICF) is the fluid within cells. The extracellular fluid (ECF) includes both the blood plasma and the interstitial fluid (IF) between the cells.*

Although water makes up the largest percentage of body volume, it is not actually pure water, but rather a mixture of dissolved substances (***solutes***) that are critical to life. These solutes include ***electrolytes,*** substances that dissociate into charged ions when dissolved in water. For example, sodium chloride (the chemical name for table salt) dissociates into sodium (Na^+) and chloride (Cl^-) in water. In extracellular fluid, sodium is the major positively-charged electrolyte (or ***cation***), and chloride (Cl^-) is the major negatively-charged electrolyte (or ***anion***). Potassium (K^+) is the major cation inside cells. Together, these electrolytes are involved in many body functions, including water balance, acid-base balance, and assisting in the transmission of electrical impulses along cell membranes in nerves and muscles.

Fluid and Electrolyte Balance

One of the essential homeostatic functions of the body is to maintain fluid and electrolyte balance within cells and their surrounding environment. Cell membranes are ***selectively permeable***: Water can move freely through the cell membrane, while other substances, such as electrolytes, require special transport proteins, channels, and often energy. The movement of water between the intracellular and extracellular fluid happens by ***osmosis***, which is simply the movement of water through a selectively permeable membrane from an area where solutes are less concentrated to an area where solutes are more concentrated (Figure 8.7).

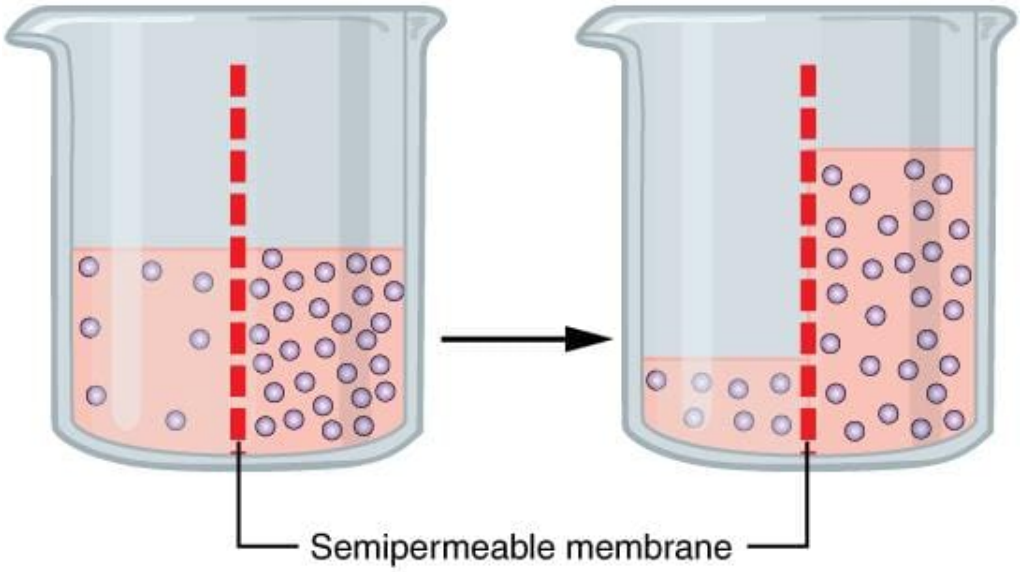


Figure 8.7. Osmosis is the diffusion of water through a semipermeable membrane towards higher solute concentration. If a membrane is permeable to water but not a solute, water will equalize its own concentration by diffusing to the side of lower water concentration (and thus the side of higher solute concentration). In the beaker on the left, the solution on the right side of the membrane is more concentrated with solutes; therefore, water diffuses to the right side of the beaker to equalize its concentration.

To maintain water and electrolyte balance, cells control the movement of electrolytes across their membranes, and water follows the electrolytes by osmosis. The health of the cell depends on proper fluid and electrolyte balance. If the body's fluid and electrolyte levels change too rapidly, cells can struggle to correct the imbalance quickly enough. For example, consider a person exercising strenuously, losing water and electrolytes in the form of sweat, and drinking excessive amounts of water. The excess water dilutes the sodium in the blood, leading to ***hyponatremia***, or low blood sodium concentrations. Sodium levels within the cells are now more concentrated, leading water to enter the cells by osmosis. As a result, the cells swell with water and can burst if the imbalance is severe and prolonged.

In contrast, the opposite situation can occur in a person exercising strenuously for a long duration with inadequate fluid intake. This can lead to dehydration and ***hypernatremia***, or elevated blood sodium levels. The high concentration of sodium in the extracellular fluid causes water to leave cells by osmosis, making them shrink (Figure 8.8). This scenario can also occur anytime a person is dehydrated because of significant fluid loss, such as from diarrhea and/or vomiting caused by illness.

When a person becomes dehydrated, and solutes like sodium become too concentrated in the blood, the thirst response is triggered. Sensory receptors in the thirst center in the hypothalamus monitor the concentration of solutes of the blood. If blood solutes (like sodium) increase above ideal levels, the hypothalamus transmits signals that result in a conscious awareness of thirst. The hypothalamus also communicates to the kidneys to decrease water output through the urine.

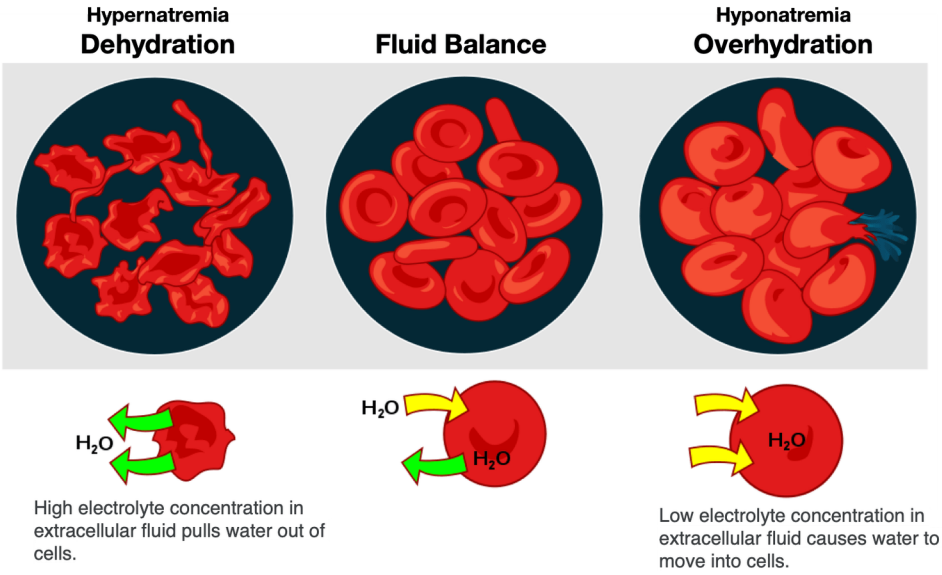


Figure 8.8. Effect of fluid imbalance on cells. With dehydration, the concentration of electrolytes becomes greater outside of cells, leading to water leaving cells and making them shrink. In fluid balance, electrolyte concentrations are in balance inside and outside of cells, so water is in balance too. During overhydration, electrolyte concentrations are low outside the cell relative to inside the cell (like in the situation of hyponatremia), so water moves into the cells, making them swell.

The cell is able to control the movement of the two major cations, sodium and potassium, with a sodium-potassium pump (Na^+/K^+ pump). This pump transports sodium out of cells while moving potassium into cells.

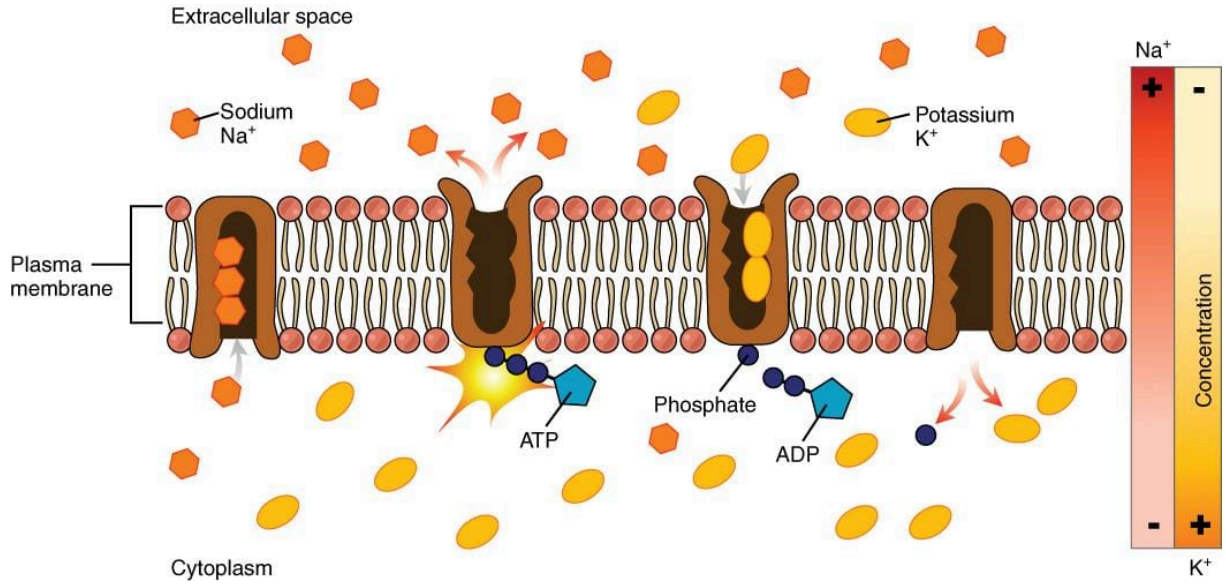


Figure 8.9. The sodium-potassium pump is found in many cell (plasma) membranes. Powered by ATP, the pump moves sodium and potassium ions in opposite directions, each against its concentration gradient. In a single cycle of the pump, three sodium ions are extruded from and two potassium ions are imported into the cell.

VIDEO: "Sodium Potassium Pump," by McGraw Hill Animations, YouTube (June 4, 2017), 2:02 minutes.

YouTube Video

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The Na^+/K^+ pump is an important ion pump found in the membranes of many types of cells and is particularly abundant in nerve cells. When a nerve cell is stimulated (e.g., the touch of a hand), there is an influx of sodium ions into the nerve cell. Similar to how a current moves along a wire, a sodium current moves along a nerve cell.

Stimulating a muscle contraction also involves the movement of sodium ions. For a muscle to contract, a nerve impulse travels to a muscle. The movement of the sodium current in the nerve signals the muscle cell membrane to open and sodium rushes in, creating another current that travels along the muscle and eventually leading to muscle contraction. In both nerve and muscle cells, the sodium that went in during a stimulus now has to be moved out by the sodium-potassium pump in order for the nerve and muscle cell to be stimulated again.

Sodium

Although sodium often gets villianized because of its link to hypertension, it is an essential nutrient that is vital for survival. As previously discussed, it is not only important for fluid balance, but also nerve impulse transmission and muscle contraction.

Food Sources of Sodium

Sodium can be found naturally in a variety of whole foods, but most sodium in the typical American diet comes from processed and prepared foods. Manufacturers add salt to foods to improve texture and flavor, and also to act as a preservative. Even foods that you wouldn't consider to be salty, like breakfasts cereals, can have greater than 10% of the DV for sodium. Most Americans exceed the adequate intake recommendation of 1500 mg per day, averaging 3,440 mg per day.[1] The sources of sodium in the American diet are shown below.

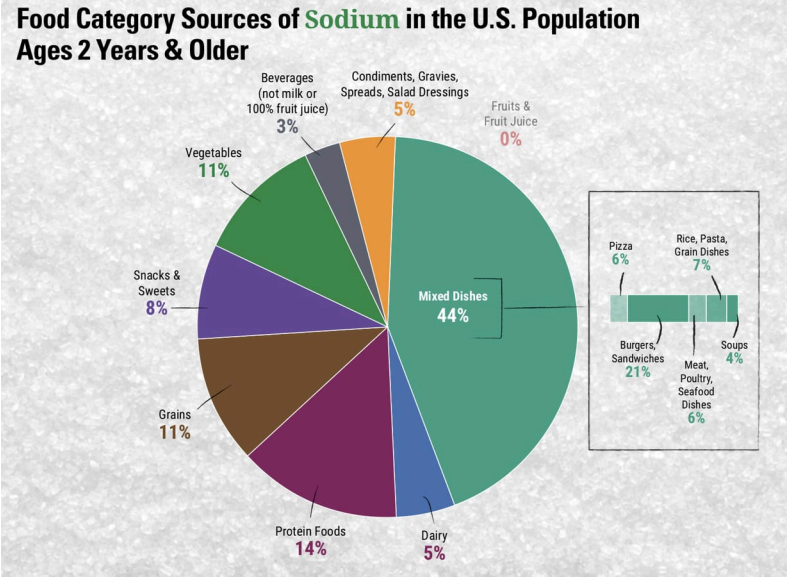


Figure 8.10. Food category sources of sodium in the U.S. population, ages 2 years and older. [1] *The largest source of sodium (44%) is mixed dishes such as burgers, sandwiches, pasta dishes and pizza.*

This slideshow from WebMD, "Sources of Salt and How to Cut Back," offers some tools for reducing dietary sodium.

Sodium Deficiency and Toxicity

Deficiencies of sodium are extremely rare since sodium is so prevalent in the American diet. It is too much sodium that is the main concern. High dietary intake of sodium is one risk factor for ***hypertension***, or high blood pressure. In many people with hypertension, cutting salt intake can help reduce their blood pressure. However, studies have shown that this isn't always the case. According to Harvard Medical School, "About 60% of people with high blood pressure are thought to be ***salt-sensitive*** — [a trait that means your blood pressure increases with a high-sodium diet]. So are about a quarter of people with normal blood pressure, although they may develop high blood pressure later, since salt sensitivity increases with age and weight gain."[2] Genetics, race, sex, weight, and physical activity level are determinants of salt sensitivity. African Americans, women, and overweight individuals are more salt-sensitive than others.

The Dietary Approaches to Stop Hypertension (DASH) is an eating pattern that has been tested in randomized controlled trials and shown to reduce blood pressure and LDL cholesterol levels, resulting in decreased cardiovascular disease risk.[1] According to the Dietary Guidelines for Americans, "The DASH Eating Plan is high in vegetables, fruits, low-fat dairy products, whole grains, poultry, fish, beans, and nuts and is low in sweets, sugar-sweetened beverages, and red meats. It is low in saturated fats and rich in potassium, calcium, and magnesium, as well as dietary fiber and protein. It also is lower in sodium than the typical American diet, and includes menus with two levels of sodium, 2,300 and 1,500 mg per day." Additional details on DASH are available on the website of the National Heart, Lung, and Blood Institute website.

Potassium

Potassium is present in all body tissues and is the most abundant positively charged electrolyte in the intracellular fluid. As discussed previously, it is required for proper fluid balance, nerve transmission, and muscle contraction.[5]

Food Sources of Potassium

Potassium is found in a wide variety of fresh plant and animal foods. Fresh fruits and vegetables are excellent sources of potassium, as well as dairy products (e.g., milk and yogurt), beans (e.g., lentils and soybeans), and meat (e.g., salmon and beef).[5]

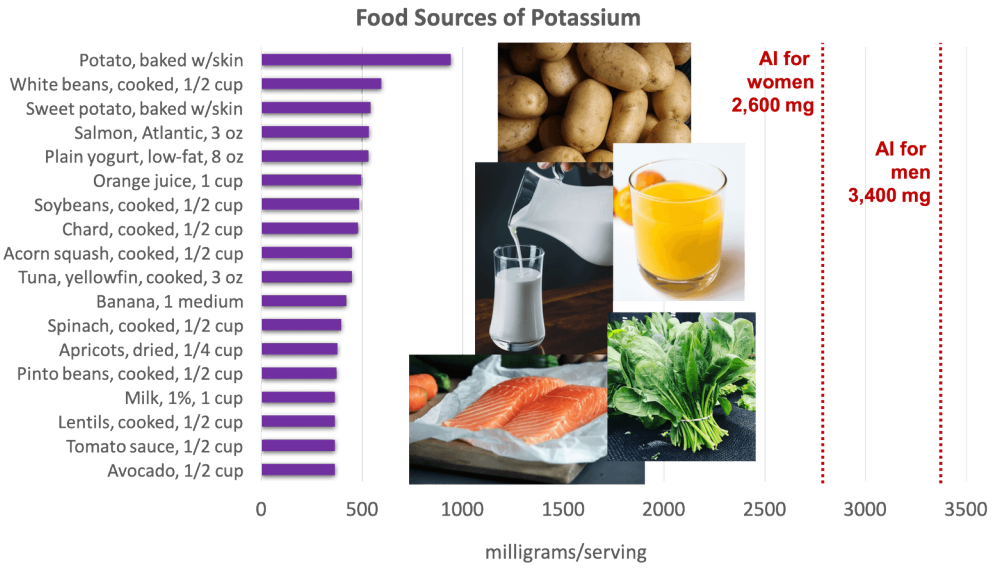


Figure 8.11. Dietary sources of potassium. Source: *Dietary Guidelines for Americans, 2015-2020*

The 2015–2020 Dietary Guidelines for Americans identifies potassium as a "nutrient of public health concern," because dietary surveys consistently show that people in the United States consume less potassium than is recommended.[1] This is a nutritional

gap that must be corrected through food since most dietary supplements do not contain significant amounts of potassium.

Potassium Deficiency and Toxicity

Low potassium intake may have negative health implications on blood pressure, kidney stone formation, bone mineral density, and type 2 diabetes risk. Although there is a large body of evidence that has found a low potassium intake increases the risk of hypertension, especially when combined with high sodium intake, and higher potassium intake may help decrease blood pressure, especially in salt-sensitive individuals, the body of evidence to support a cause-and-effect relationship is limited and inconclusive.[6] However, it is important to remember that a lack of evidence does not mean there is a lack of effect of potassium intake on chronic disease outcomes. This is an area that needs more research to determine the effect dietary potassium has on chronic disease risk.

There is no UL set for potassium since healthy people with normal kidney function can excrete excess potassium in the urine, and therefore high *dietary* intakes of potassium do not pose a health risk.[7] However, the absence of a UL does not mean that there is no risk from excessive *supplemental* potassium intake, and caution is warranted against taking high levels of supplemental potassium.[8]

Chloride

Chloride helps with fluid balance, acid-base balance, and nerve cell transmission. It is also a component of hydrochloric acid, which aids digestion in the stomach.[9]

Table salt is 60% chloride, so most chloride in the diet comes from salt. Each teaspoon of salt contains 3.4 grams of chloride. The chloride AI for adults is 2.3 grams. Therefore, the chloride requirement can be met with less than a teaspoon of salt each day. Other dietary sources of chloride include tomatoes, lettuce, olives, celery, rye, whole-grain foods, and seafood.

Chloride deficiency is rare since most foods containing sodium also provide chloride, and sodium intake in the American diet is high.[9]

Attributions:

- Zimmerman, M., & Snow, B. Nutrients Important to Fluid and Electrolyte Balance. In *An Introduction to Nutrition* (v. 1.0). https://2012books.lardbucket.org/books/an-introduction-to-nutrition/index.html, CC BY-NC-SA 3.0
- "Fluid, Electrolyte, and Acid-Base Balance," unit 26 from J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix, Anatomy and Physiology, CC BY 4.0
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- [1]U.S. Department of Health and Human Services, U.S. Department of Agriculture. 2015–2020 Dietary Guidelines for Americans. 2015.
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Images:

- Figure 8.6. “Fluid Compartments in the Human Body” by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix, Anatomy and Physiology, OpenStax, licensed under CC BY 4.0
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10.3.1: Sodium

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

Other Functions of Sodium in the Body

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

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

Sodium Imbalances

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

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

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

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

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

Needs and Dietary Sources of Sodium

The IOM has set an AI level for sodium for healthy adults between the ages of nineteen and fifty at 1,500 milligrams (Table 3.2). Table salt is approximately 40 percent sodium and 60 percent chloride. As a reference point, only ⅔ teaspoon of salt is needed in the diet to meet the AI for sodium. The AI takes into account the amount of sodium lost in sweat during recommended physical activity levels and additionally provides for the sufficient intake of other nutrients, such as chloride. The Tolerable Upper Intake Level (UL) for sodium is 2,300 milligrams per day for adults. (Just over 1 teaspoon of salt contains the 2,300 milligrams of sodium recommended). The UL is considered appropriate for healthy individuals but not those with hypertension (high blood pressure). The IOM estimates that greater than 95 percent of men and 75 percent of women in America consume salt in excess of the UL. Many scientific studies demonstrate that reducing salt intake prevents hypertension, is helpful in reducing blood pressure after hypertension is diagnosed, and reduces the risk for cardiovascular disease. The IOM recommends that people over fifty, African Americans, diabetics, and those with chronic kidney disease should consume no more than 1,500 milligrams of sodium per day. The American Heart Association (AHA) states that all Americans, not just those listed, should consume less than 1,500 milligrams of sodium per day to prevent cardiovascular disease. The AHA recommends this because millions of people have risk factors for hypertension and there is scientific evidence supporting that lower-sodium diets are preventive against hypertension.

Table 10.3.1.1*: Dietary Reference Intakes for Sodium*

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

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

Food Sources for Sodium

Most sodium in the typical American diet comes from processed and prepared foods. Manufacturers add salt to foods to improve texture and flavor, and also as a preservative. The amount of salt in similar food products varies widely. Some foods, such as meat, poultry, and dairy foods, contain naturally-occurring sodium. For example, one cup of low-fat milk contains 107 milligrams of sodium. Naturally-occurring sodium accounts for less than 12 percent of dietary intake in a typical diet. For the sodium contents of various foods see Table 3.3.

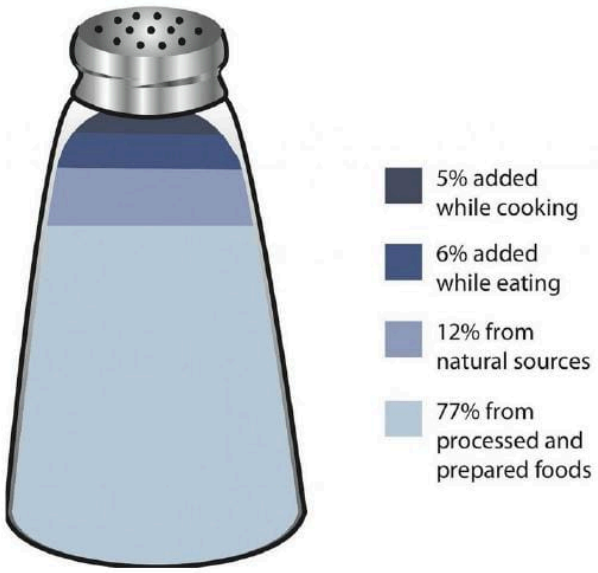


Figure 10.3.1.1: Dietary Sources of Sodium. “Food Eat Salt” by Clker-Free-Vector-Images / Pixabay License

Table 10.3.1.2: Sodium Contents of Selected Foods

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

Food Group	Serving Size	Sodium (mg)
Fresh tuna	3 oz.	50
Dry-roasted peanuts	1 c.	986
American cheese	1 oz.	406
Tap water	8 oz.	12

Sodium on the Nutrition Facts Panel



Figure 10.3.1.2: Nutrition Label. Sodium levels in milligrams is a required listing on a Nutrition Facts label.

The Nutrition Facts panel displays the amount of sodium (in milligrams) per serving of the food in question (Figure 10.3.1.2). Food additives are often high in sodium, for example, monosodium glutamate (MSG) contains 12 percent sodium. Additionally, baking soda, baking powder, disodium phosphate, sodium alginate, and sodium nitrate or nitrite contain a significant proportion of sodium as well. When you see a food's Nutrition Facts label, you can check the ingredients list to identify the source of the added sodium. Various claims about the sodium content in foods must be in accordance with Food and Drug Administration (FDA) regulations (Table 10.3.1.3).

Table 10.3.1.3: Food Packaging Claims Regarding Sodium

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

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

2011.

Tools for Change

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

Salt Substitutes

For those with hypertension or those looking for a way to decrease salt use, using a salt substitute for food preparation is one option. However, many salt substitutes still contain sodium, just in lesser amounts than table salt. Also, remember that most salt in the diet is not from table-salt use, but from processed foods. Salt substitutes often replace the sodium with potassium. People with kidney disorders often have problems getting rid of excess potassium in the diet and are advised to avoid salt substitutes containing potassium. People with liver disorders should also avoid salt substitutes containing potassium because their treatment is often accompanied by potassium dysregulation. Table 10.3.1.4 displays the sodium and potassium amounts in some salt substitutes.

Table 10.3.1.4: Salt Substitutes

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

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

Alternative Seasonings

Table salt may seem an essential ingredient of good food, but there are others that provide alternative taste and zest to your foods. See Table 10.3.1.5 for an AHA list of alternative food seasonings.

Table 10.3.1.5 Salt Alternatives

Seasoning	Foods
Allspice	Lean ground meats, stews, tomatoes, peaches, applesauce, cranberry sauce, gravies, lean meat

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

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

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10.3.2: Potassium

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

Other Functions of Potassium in the Body

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

Imbalances of Potassium

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

Needs and Dietary Sources of Potassium

The updated potassium AIs are 400 mg daily for infants 0-6 months; 860 mg daily for infants 7-12 months; 2,000 mg daily for children ages 1-3; and 2,300 mg daily for ages 4-8. The potassium AIs for other age groups range from 2,300 to 3,400 mg per day, based on sex and life-stage groups. The potassium AIs in this report are lower than those established in 2005. This difference is due, in part, to the expansion of the DRI model in which consideration of chronic disease risk reduction was separate from consideration of adequacy. The AIs for tge age groups are listed in Table 10.3.2.1.

Table

:
Updated (2019) Adequate Intakes (AIs) for Potassium* [11]

Age	*Male*	*Female*	*Pregnancy*	*Lactation*
Birth to 6 months	*400 mg*	*400 mg*		
7–12 months	*860 mg*	*860 mg*		
1–3 years	*2,000 mg*	*2,000 mg*		
4–8 years	*2,300 mg*	*2,300 mg*		
9–13 years	*2,500 mg*	*2,300 mg*		
14–18 years	*3,000 mg*	*2,300 mg*	*2,600 mg*	*2,500 mg*
19–50 years	*3,400 mg*	*2,600 mg*	*2,900 mg*	*2,800 mg*
51+ years	*3,400 mg*	*2,600 mg*		

National Academies of Sciences, Engineering, and Medicine. Dietary Reference Intakes for Sodium and Potassium. Washington, DC; The National Academies Press; 2019. https://nap.nationalacademies.org/ca...-and-potassium. Accessed October 2, 2025.

Food Sources for Potassium

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

Bioavailability

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

Query 10.3.2.1

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10.3.3: Chloride

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

Chloride's Role in Fluid Balance

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

Cystic Fibrosis

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

Other Functions of Chloride

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

Chloride Imbalances

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

Needs and Dietary Sources of Chloride

Most chloride in the diet comes from salt. (Salt is 60 percent chloride.) A teaspoon of salt equals 5,600 milligrams, with each teaspoon of salt containing 3,400 milligrams of chloride and 2,200 milligrams of sodium. The chloride AI for adults, set by the IOM, is 2,300 milligrams. Therefore just ⅔ teaspoon of table salt per day is sufficient for chloride as well as sodium. The AIs for other age groups are listed in Table 10.3.3.1.

Table 10.3.3.1: Adequate Intakes for Chloride

Age Group	mg/day
Infants (0–6 months)	180
Infants (6–12 months)	570
Children (1–3 years)	1,500
Children (4–8 years)	1,900
Children (9–13 years)	2,300

Age Group	mg/day
Adolescents (14–18 years)	2,300
Adults (19–50 years)	2,300
Adults (51–70 years)	2,000
Adults (> 70 years)	1,800

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

Other Dietary Sources of Chloride

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

Bioavailability

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

Query 10.3.3.1

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10.3.4: Consequences of Deficiency or Excess

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

High-Hydration Status: Water Intoxication/Hyponatremia

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

Low-Hydration Status: Dehydration

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

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

Heat Stroke

Heat stroke is a life-threatening condition that occurs when the body temperature is greater than 104°F (40°C). It is the result of the body being unable to sufficiently cool itself by thermoregulatory mechanisms. Dehydration is a primary cause of heat stroke as there are not enough fluids in the body to maintain adequate sweat production, and cooling of the body is impaired. Signs and symptoms are dry skin (absence of sweating), dizziness, trouble breathing, rapid pulse, confusion, agitation, seizures, coma, and possibly death. Dehydration may be preceded by heat exhaustion, which is characterized by heavy sweating, rapid breathing, and fast pulse. The elderly, infants, and athletes are the most at risk for heat stroke.

Hypertension

Blood pressure is the force of moving blood against arterial walls. It is reported as the systolic pressure over the diastolic pressure, which is the greatest and least pressure on an artery that occurs with each heartbeat. The force of blood against an artery is measured with a device called a sphygmomanometer. The results are recorded in millimeters of mercury, or mmHg. A desirable blood pressure is less than 120/80 mm Hg. Hypertension is the scientific term for high blood pressure and defined as a sustained blood pressure of 130/80 mm Hg or greater.[1] Hypertension is a risk factor for cardiovascular disease, and reducing blood pressure has been found to decrease the risk of dying from a heart attack or stroke. The Centers for Disease Control and Prevention (CDC) reported that in 2007–2008 approximately 33 percent of Americans were hypertensive.[2]The percentage of people with hypertension increases to over 60 percent in people over the age of sixty.



Figure 10.3.4.1: Measuring Blood Pressure. Testing a GIs blood pressure at Guantanamo by Charlie Helmholt / Public Domain

There has been much debate about the role sodium plays in hypertension. In the latter 1980s and early 1990s the largest epidemiological study evaluating the relationship of dietary sodium intake with blood pressure, called INTERSALT, was completed and then went through further analyses.[3][4]

More than ten thousand men and women from thirty-two countries participated in the study. The study concluded that a higher sodium intake is linked to an increase in blood pressure. A more recent study, involving over twelve thousand US citizens, concluded that a higher sodium-to-potassium intake is linked to higher cardiovascular mortality and all-causes mortality.[5]

The DASH-Sodium trial was a clinical trial which evaluated the effects of a specified eating plan with or without reduced sodium intake. The DASH diet is an eating plan that is low in saturated fat, cholesterol, and total fat. Fruits, vegetables, low-fat dairy foods, whole-grain foods, fish, poultry, and nuts are emphasized while red meats, sweets, and sugar-containing beverages are mostly avoided. In this study, people on the low-sodium (1500 milligrams per day) DASH diet had mean systolic blood pressures that were 7.1 mmHg lower than people without hypertension not on the DASH diet. The effect on blood pressure was greatest in participants with hypertension at the beginning of the study who followed the DASH diet. Their systolic blood pressures were, on average, 11.5 mmHg lower than participants with hypertension on the control diet.[6]

Following the DASH diet not only reduces sodium intake, but also increases potassium, calcium, and magnesium intake. All of these electrolytes have a positive effect on blood pressure, although the mechanisms by which they reduce blood pressure are largely unknown.

While some other large studies have demonstrated little or no significant relationship between sodium intake and blood pressure, the weight of scientific evidence demonstrating low-sodium diets as effective preventative and treatment measures against hypertension led the US government to pass a focus on salt within the Consolidated Appropriations Act of 2008. A part of this act tasked the CDC, under guidance from the IOM, to make recommendations for Americans to reduce dietary sodium intake. This task is ongoing and involves “studying government approaches (regulatory and legislative actions), food supply approaches (new product development, food reformulation), and information/education strategies for the public and professionals.”[7]

Try for Yourself

The National Heart, Lung, and Blood Institute has prepared an informative fact sheet on the DASH diet: http://www.nhlbi.nih.gov/health/public/heart/hbp/dash/new_dash.pdf.
Use the food-group charts to help design a daily menu that follows the DASH eating plan.

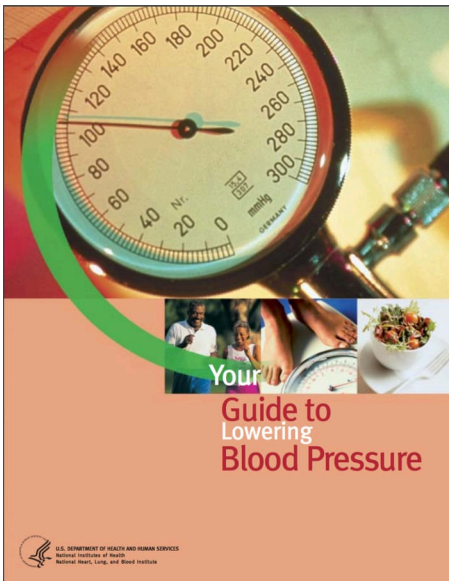


Figure 10.3.4.2: “Your Guide to Lowering Blood Pressure”. US Department of Health Services

Salt Sensitivity

High dietary intake of sodium is one risk factor for hypertension and contributes to high blood pressure in many people. However, studies have shown that not everyone’s blood pressure is affected by lowering sodium intake. About 10 to 20 percent of the population is considered to be salt-sensitive, meaning their blood pressure is affected by salt intake. Genetics, race, gender, weight, and physical activity level are determinants of salt sensitivity. African Americans, women, and overweight individuals are more salt-sensitive than others. Also, if hypertension runs in a person’s family, that person is more likely to be salt-sensitive. Because reducing dietary salt intake will not work for everyone with hypertension or a risk for developing the condition, there are many opponents of reducing dietary salt intake at the national level. Among such opponents is the Salt Institute, a nonprofit trade organization that states, “No evidence demonstrates that current salt intake levels lead to worse health outcomes such as more heart attacks or higher cardiovascular mortality.”[8]

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10.4: Minerals and Bone Health — Ca, Mg, P, F

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10.4.1: Introduction to Bone Health

The human skeleton consists of 206 bones and other connective tissues that together support and protect many organs, produce red and white blood cells, and act as a storage depot for minerals such as calcium, phosphorus, and magnesium. Although bones may look inactive at first glance, they are living tissues that are dynamic and in a constant state of breaking down and rebuilding to withstand mechanical forces. Bones also contain a complex network of canals, blood vessels, and nerves that allow for nutrient transport and communication with other organ systems.

Nutrition influences all body systems, and the skeletal system is no exception. Our lifestyle choices impact the health of our bones. In this section, we will look at how bone forms across the lifecycle and discuss the complex interactions of nutrients, hormones, genetics, and environmental factors that impact bone health.

What Is Bone?

Bone is a living tissue, made mostly of ***collagen***, a protein that provides a soft framework, and minerals like calcium phosphate that form tiny crystals (called ***hydroxyapatite***) around the collagen fibers. These inorganic minerals harden the collagen framework and provide strength. The combination of collagen and minerals makes bone both flexible and strong, which allows it to withstand stress.

Most bones contain two types of tissue, compact and spongy tissue, but their distribution and concentration vary based on the bone's function. ***Spongy bone*** (also known as trabecular bone) is 50 to 90 percent porous and appears as a lattice-like structure under a microscope. It makes up about 20 percent of the adult skeleton and is found at the ends of long bones, in the cores of vertebrae, and in the pelvis, as it supports shifts in weight distribution. ***Compactbone*** (also known as cortical bone) is dense so that it can withstand compressive forces. It is only 10 percent porous, and it looks similar to the rings in a tree trunk, with many concentric circles sandwiched together. Compact bone tissue makes up approximately 80 percent of the adult skeleton and surrounds all spongy tissue.

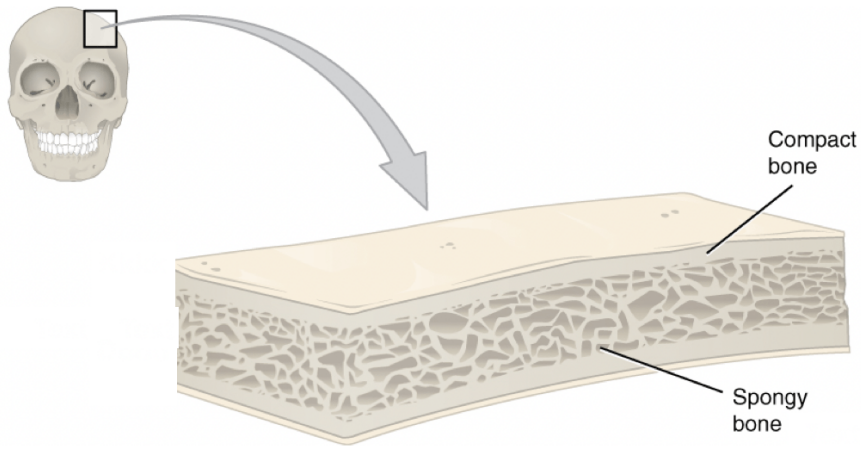


Figure 9.1. This cross-section of a flat bone from the skull shows the spongy bone lined on either side by a layer of compact bone.

Bone Growth, Modeling, and Remodeling

Bones change in shape, size, and position throughout the life cycle. During infancy, childhood, and adolescence, bones are continuously growing and changing shape through two processes: growth (or ***ossification***) and ***modeling***. In the process of modeling, bone tissue is dismantled at one site and built up at a *different* site, which influences the *shape* of the bone. During childhood and adolescence, more bone is deposited than dismantled, so bones grow in both size and density, reaching 90

percent of peak bone mass by age 18 in girls and age 20 in boys.[2] ***Peak bone mass*** is reached by age 30, at which point bones have reached their maximum strength and density. Factors affecting peak bone mass include sex, race, hormones (e.g., estrogen and testosterone), nutrition (e.g., calcium and vitamin D intake), physical activity, and behavioral factors like smoking. These factors will be discussed in more detail when we discuss osteoporosis.

In adulthood, our bones stop growing and modeling, but they continue to go through a process of bone ***remodeling***, in which bone tissue is degraded and built up at the *same* location. About 10 percent of bone tissue is remodeled each year in adults. Bones adapt their structure to the forces acting upon them, even in adulthood. This is why physical activity increases bone strength, especially when it involves weight-bearing activities. For example, tennis players can have measurably higher bone mass in the arm they use for play compared with the other arm.[3] Ultimately, bones adapt their shape and size to accommodate function.

The dynamic nature of bone means that new tissue is constantly formed, and old, injured, or unnecessary bone is dissolved for repair or for calcium release. The cell type responsible for bone ***resorption***, or breakdown, is the ***osteoclast***. Osteoclasts are continually breaking down old bone tissue. Another type of cell, called ***osteoblasts,*** are continually forming new bone. The ongoing balance between osteoblasts and osteoclasts is responsible for the constant but subtle reshaping of bone. The decline in bone mass after age 40 occurs because the rate of bone loss is greater than the rate of bone formation. This means that osteoclast-mediated bone degradation exceeds that of the bone-building activity of osteoblasts. How much bone is lost in adulthood depends on peak bone mass reached in early adulthood and other risk factors, as we'll discuss next.

Osteoporosis

Osteoporosis is a bone disease that occurs when bone density or bone mass decreases. The bone becomes thinner and more porous and is therefore more susceptible to breaking. According to the National Institute of Arthritis and Musculoskeletal and Skin Diseases, more than 53 million people in the U.S. either have osteoporosis already or are at high risk of developing it due to low bone mass.[1]

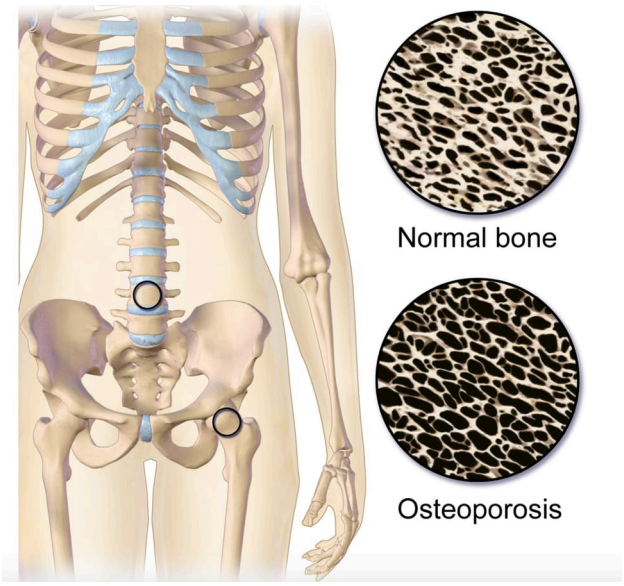


Figure 9.2. Osteoporosis. This illustration shows the difference between the structure of normal bone, which is less porous, and bone with osteoporosis, which is more porous. The two circles located on the spine and hip represent the location of the images.

Bone loss usually occurs without symptoms, so osteoporosis is often called a silent disease. It can go undetected until bones become so weak that they fracture due to a sudden strain, bump, or fall.

One way bone health can be assessed is by measuring bone mineral density. A ***bone mineral density (BMD***) test can detect osteoporosis and predict the risk of bone fracture. The most common tool used to measure BMD is called ***dual energy X-ray absorptiometry (DXA)***. This method can measure bone density over the entire body, but most often the DXA scan focuses on measuring BMD in the hip and the spine. These measurements are then used as indicators of overall bone strength and health. DXA is painless, non-invasive, uses low doses of radiation, and is the most accurate way to measure BMD.

An individual's chances of developing osteoporosis depend on several risk factors, some of which are controllable and some of which are not. It is thought that genetic factors (such as sex and race) may account for up to 75 percent of bone mass, and lifestyle factors (such as diet and exercise habits) account for the remaining 25 percent.[2]

Osteoporosis risk factors that are biological and can't be controlled:

- **Body frame size-** People with small frames are at higher risk for osteoporosis.
- **Race-** Caucasian and Asian populations are at higher risk of osteoporosis compared to African American and Hispanic populations, which are at lower risk.[1]
- **Family history**– Having a family member with osteoporosis may increase risk, as heredity seems to play a part in the development of osteoporosis.
- **Age-** After age 40, bone mass declines due to bone breakdown exceeding bone formation. Therefore, any person over the age of 40 has an increased likelihood of developing osteoporosis compared with a younger person. Starting out with a higher peak bone mass in early adulthood enables you to lose more bone during the aging process and not develop osteoporosis.
- **Sex-** Females, on average, have a lower peak bone mass compared with males (see Figure 9.3) and a much greater risk of developing osteoporosis, in part because of hormone levels.
- **Hormones-** The female hormone estrogen and the male hormone testosterone both help to increase peak bone mass. Estrogen is the primary female reproductive hormone, and it stimulates bone building and reduces bone breakdown. When women go through menopause (usually around age 50), they experience a natural decline in estrogen levels, which accelerates bone loss and increases the risk of developing osteoporosis (Figure 9.3).

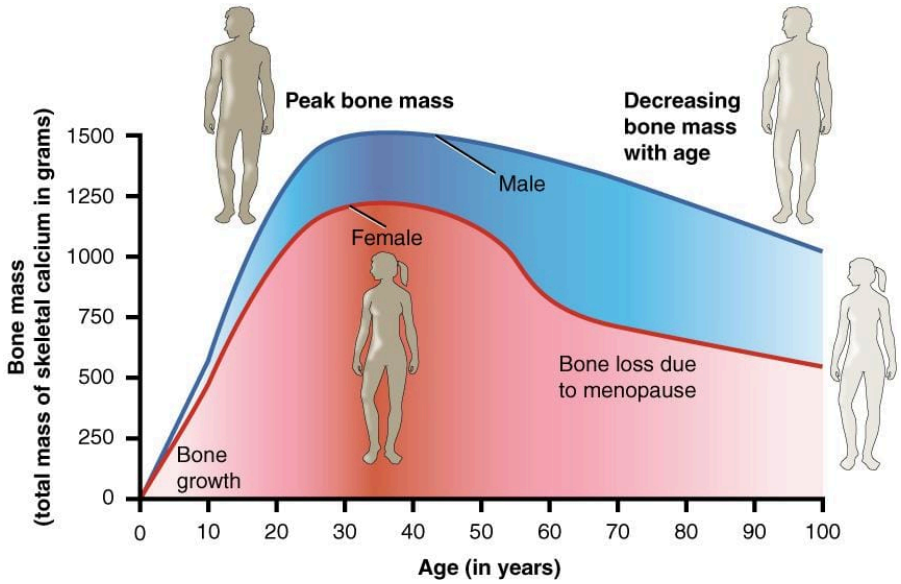


Figure 9.3. Age and bone mass. Bone density peaks at about *30 years of age , and women lose bone mass more rapidly than men, particularly around menopause.*

Risk factors that can be controlled:

- **Physical inactivity-** Physical inactivity lowers peak bone mass, decreases BMD at all ages, and is linked to an increase in fracture risk, especially in the elderly. Regular exercise can help individuals achieve greater peak bone mass, prevents bone loss for women and men age 30 and older, and maintains strength and balance to help prevent falls later in life. The best activities for stimulating new bone are weight-bearing exercise, such as walking, hiking, and dancing, and resistance exercises like weight lifting.
- **Nutrition-** Ensuring adequate nutrition is a key component in maintaining bone health. Having low dietary intakes of calcium and vitamin D are strong risk factors for developing osteoporosis. Protein is also important during childhood and adolescence for proper bone development, and in older age to preserve bone mass.[4]
- **Smoking-** Smoking cigarettes has long been known to correlate to a decrease in bone mass and an increased risk of osteoporosis and fractures. However, because people who smoke are more likely to be physically inactive and have poor diets, it is difficult to determine whether smoking itself causes osteoporosis. Smoking is also linked to earlier menopause, and therefore the increased risk of developing osteoporosis among female smokers may also be attributed, at least in part,

to having reduced estrogen production at an earlier age. However, studies have also shown that tobacco smoke and nicotine can directly impact bone metabolism.[5]

- **Alcohol intake-** Alcohol intake may also affect bone health, although this seems to depend on the amount consumed. Light to moderate alcohol intake (two drinks or less per day) has been shown in some studies to be associated with an increase in bone density and a decreased risk of developing osteoporosis. However, excessive alcohol intake is associated with decreased bone density and increased fracture risk, although this may be due in part to other lifestyle factors, such as poor diet and less physical activity.[6]
- **Being underweight-** Being underweight significantly increases the risk of developing osteoporosis, because people who are underweight often have a smaller frame size and a lower peak bone mass. The most striking relationship between being underweight and bone health is seen in people with anorexia nervosa. Anorexia nervosa is strongly correlated with low peak bone mass, and more than 50 percent of men and women who have this illness develop osteoporosis, often very early in life.

The changeable risk factors for osteoporosis provide ways for people to improve their bone health, even though some people may be genetically predisposed to the disease. Prevention of osteoporosis begins early in life since this is a critical time of bone growth. Eating a balanced diet that provides adequate amounts of calcium, vitamin D, and protein is important for bone health throughout the life cycle. Participating in exercise such as walking, hiking, and weight lifting, and refraining from risky behaviors like smoking and excessive drinking are all behaviors that will help protect bones.

Attributions:

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Images:

- Figure 9.1. "Anatomy of a Flat Bone" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix, Anatomy and Physiology, OpenStax, licensed under CC BY 4.0
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10.4.2: Calcium — Critical for Bones and Throughout the Body

As discussed on the previous page, bones are made up of two components: inorganic minerals and a protein matrix. Minerals, which make up 65% of bone tissue, are what gives bones their hardness. Calcium and phosphorus together form hydroxyapatite crystals, the main mineral component of bone. Other minerals, including magnesium, fluoride, sodium, and potassium, play supporting roles. This page focuses on calcium, and we'll cover potassium, magnesium, and fluoride on the following page. (Sodium and potassium are covered in the electrolyte section of this text.)

Calcium Functions and Regulation

Calcium is the most abundant mineral in the body. Most of the body's calcium—more than 99% of it—is stored in bone, where it's important for bone strength and structure. The remaining 1% of the body's calcium is found in the blood and soft tissues, but it is here that calcium performs its most critical functions. For example, calcium is required for the transmission of every nerve impulse, electrical signals sent from one nerve cell to another. It's also required for every cycle of muscle contraction and relaxation. With inadequate calcium, muscles can't relax, and instead become stiff and contract involuntarily, a condition known as ***tetany***. Calcium also plays vital roles in blood pressure regulation, blood clotting, enzyme activation, hormone secretion, and signaling between cells.[1]

The many roles of calcium around the body are critical to daily survival, so maintaining homeostasis, or a steady state, of blood calcium levels is a high priority. The body rigorously controls blood calcium levels in a very tight range. If blood calcium drops, your body initiates several mechanisms to restore homeostasis, including drawing calcium from the bone. While the calcium stored in bone is important for long-term strength and structure of bone, it also serves as a calcium reserve that can be drawn upon to support the vital functions of calcium in the body, should blood calcium drop too low.

Two endocrine glands are key players in the regulation of blood calcium concentrations: the thyroid gland and parathyroid glands. The ***thyroid gland*** is a small, butterfly-shaped gland located at the base of the neck. It secretes a hormone called ***calcitonin***. There are four ***parathyroid glands***, each about the size of a pea and located at the back of the thyroid gland. They secrete a hormone called ***parathyroid hormone (PTH)***.

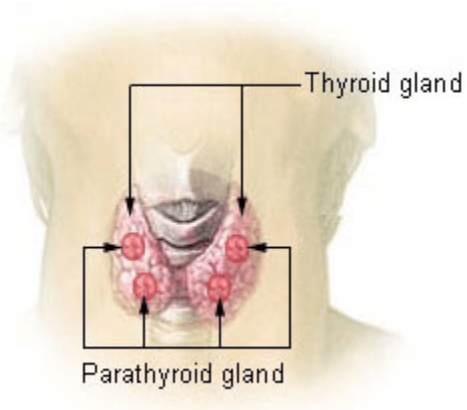


Figure 9.4. The thyroid and parathyroid glands are located at the back of the neck.

Let's take a closer look at how the body regulates blood calcium levels. If the blood calcium concentration drops too low, the parathyroid glands release ***parathyroid hormone***, or PTH. **PTH then acts in several ways to increase blood calcium levels**:

1. PTH stimulates the activity of osteoclasts to release calcium from bone.
2. PTH acts on the kidney to reduce the amount of calcium lost in the urine, returning more to circulation.
3. PTH stimulates enzymes in the kidney that convert vitamin D to its active form, also called ***calcitriol***. Activated vitamin D acts on the intestine to increase the absorption of calcium. Vitamin D also works together with PTH to stimulate release of calcium from the bone and reduce calcium loss in urine.

Once blood calcium levels are normal, PTH levels drop, turning off all of these mechanisms of increasing calcium.

On the other hand, **if blood calcium levels become too high**, the thyroid gland releases calcitonin, which inhibits the release of calcium from the bone and increases calcium excretion from the kidneys. These mechanisms help to restore normal blood calcium concentrations, after which calcitonin levels drop again.

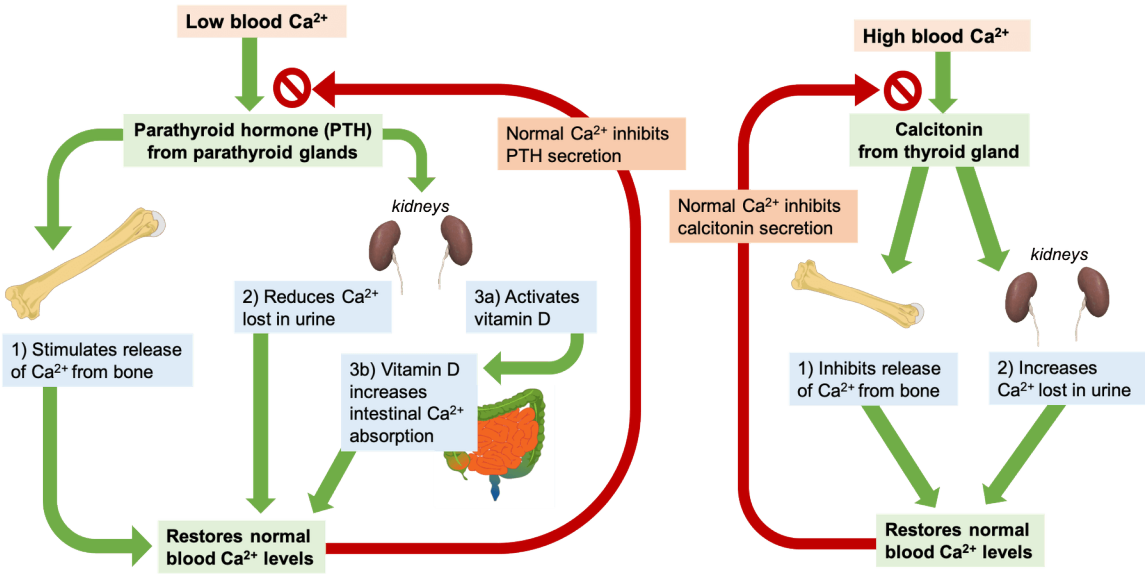


Figure 9.5. Blood calcium (Ca^{2+}) *levels are tightly regulated by PTH, vitamin D, and calcitonin.*

Through these two opposing pathways—PTH and vitamin D for raising blood calcium and calcitonin for lowering blood calcium—the body can very effectively maintain blood calcium homeostasis. This system is dependent upon stored calcium in bone, which is sacrificed when needed to ensure adequate blood calcium. In the short-term, this isn't a problem, because bone remodeling allows you to replace calcium in the bone. However, in the long-term, inadequate dietary calcium means you continuously draw down the calcium stores in your bones, resulting in declining bone mineral density and increased risk of fracture.

Calcium requirements are highest for children and adolescents, who are growing and building bones, and for older adults, who are losing bone density. The RDA for calcium for children 9 to 13 years old and teens 14 to 18 years old is 1,300 milligrams per day. The RDA for adults is 1,000 mg per day but increases to 1,200 mg per day for women ages 51 and up and for men age 71 and older.

Dietary Sources of Calcium

In the typical American diet, calcium is obtained mostly from dairy products. A slice of cheddar or Swiss cheese contains over 200 milligrams of calcium. One cup of milk contains approximately 300 milligrams of calcium, which is about a third of the RDA for calcium for most adults. Foods fortified with calcium such as cereals, soy milk and other plant-based beverages, and orange juice also provide one third or greater of the calcium RDA. Smaller amounts of calcium are naturally present in plant-based foods such as legumes, leafy greens, and nuts, and with careful planning, adequate calcium can be obtained from non-dairy sources.

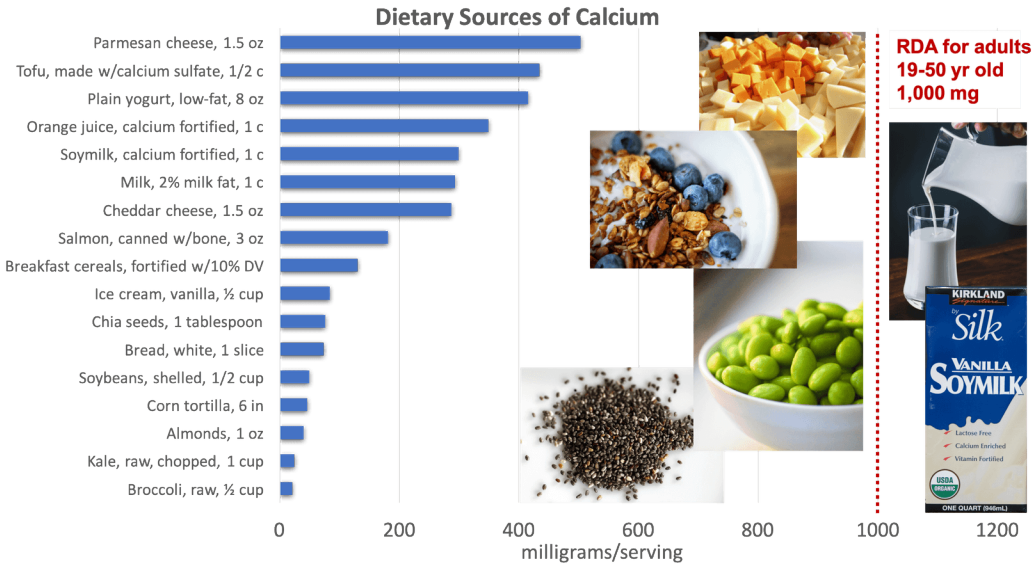


Figure 9.6. Dietary sources of calcium. *Examples of good sources pictured include cheese, milk, fortified soymilk, yogurt (with almond granola), edamame, and chia seeds. Source: NIH Office of Dietary Supplements and Dietary Guidelines for Americans, 2015-2020* .

Calcium bioavailability, or the amount of dietary calcium that is absorbed from the intestine into the bloodstream, can vary significantly. In general, calcium absorption is highest in infants and young children—who need relatively high amounts of calcium for building bone—and declines with age. With higher calcium intake, especially from supplements, bioavailability decreases in order to prevent excessive calcium absorption. Some chemical components of plant foods, including phytic acid (found in whole grains, beans, seeds, soy, and nuts) and oxalic acid (found in spinach, collard greens, sweet potatoes, rhubarb, and beans), bind to calcium and reduce bioavailability. Despite reduced absorption, these foods can still provide a significant amount of calcium.[1]

Calcium Deficiency and Toxicity

In the short-term, there are no obvious signs of calcium deficiency. This is because the body stores so much calcium in bones, and just 1% of total body calcium is required for daily functioning. If low blood calcium does occur, symptoms include muscle cramping, numbness and tingling in fingers, convulsions, lethargy, poor appetite, and abnormal heart rhythms. Without treatment, low blood calcium can lead to death.[1]

Much more common is a long-term calcium deficiency, resulting from a continuous draw of calcium stores from the bone. This causes ***osteopenia***, or low bone mass, which can lead to osteoporosis if untreated. Osteoporosis significantly increases a person's risk of fractures. Nutrition surveys in the United States show that groups at greatest risk of dietary calcium inadequacy include adolescents and older adults, especially female teens and older women.[1]

Too much calcium can also cause problems, although this is rarely caused by excessive intake of calcium from foods. Abnormally high activity of the parathyroid gland or a parathyroid tumor can cause high blood calcium, leading to calcification or hardening of blood vessels and soft tissue and the formation of kidney stones. High calcium intake from supplements has also been associated with increased risk of kidney stones, and in some studies, increased risk of cardiovascular disease. It can also cause constipation.[1]

Attributions:

- Zimmerman, M., & Snow, B. Nutrients Important for Bone Health. In *An Introduction to Nutrition* (v. 1.0). https://2012books.lardbucket.org/books/an-introduction-to-nutrition/index.html, CC BY-NC-SA 3.0

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https://ods.od.nih.gov/factsheets/Calcium-HealthProfessional/

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10.4.3: Calcium — Additional Details

Calcium's Functional Roles

Calcium is the most abundant mineral in the body and greater than 99 percent of it is stored in bone tissue. Although only 1 percent of the calcium in the human body is found in the blood and soft tissues, it is here that it performs the most critical functions. Blood calcium levels are rigorously controlled so that if blood levels drop the body will rapidly respond by stimulating bone resorption, thereby releasing stored calcium into the blood. Thus, bone tissue sacrifices its stored calcium to maintain blood calcium levels. This is why bone health is dependent on the intake of dietary calcium and also why blood levels of calcium do not always correspond to dietary intake.

Calcium plays a role in a number of different functions in the body like bone and tooth formation. The most well-known calcium function is to build and strengthen bones and teeth. Recall that when bone tissue first forms during the modeling or remodeling process, it is unhardened, protein-rich osteoid tissue. In the osteoblast-directed process of bone mineralization, calcium phosphates (salts) are deposited on the protein matrix. The calcium salts typically make up about 65 percent of bone tissue. When your diet is calcium deficient, the mineral content of bone decreases causing it to become brittle and weak. Thus, increased calcium intake helps to increase the mineralized content of bone tissue. Greater mineralized bone tissue corresponds to a greater BMD, and to greater bone strength. The remaining calcium plays a role in nerve impulse transmission by facilitating electrical impulse transmission from one nerve cell to another. Calcium in muscle cells is essential for muscle contraction because the flow of calcium ions are needed for the muscle proteins (actin and myosin) to interact. Calcium is also essential in blood clotting by activating clotting factors to fix damaged tissue.

In addition to calcium's four primary functions calcium has several other minor functions that are also critical for maintaining normal physiology. For example, without calcium, the hormone insulin could not be released from cells in the pancreas and glycogen could not be broken down in muscle cells and used to provide energy for muscle contraction.

Maintaining Calcium Levels

Because calcium performs such vital functions in the body, blood calcium level is closely regulated by the hormones parathyroid hormone (PTH), calcitriol, and calcitonin. When blood calcium levels are low, PTH is secreted to increase blood calcium levels via three different mechanisms. First, PTH stimulates the release of calcium stored in the bone. Second, PTH acts on kidney cells to increase calcium reabsorption and decrease its excretion in the urine. Third, PTH stimulates enzymes in the kidney that activate vitamin D to calcitriol. Calcitriol is the active hormone that acts on the intestinal cells and increases dietary calcium absorption. When blood calcium levels become too high, the hormone calcitonin is secreted by certain cells in the thyroid gland and PTH secretion stops. At higher nonphysiological concentrations, calcitonin lowers blood calcium levels by increasing calcium excretion in the urine, preventing further absorption of calcium in the gut and by directly inhibiting bone resorption.

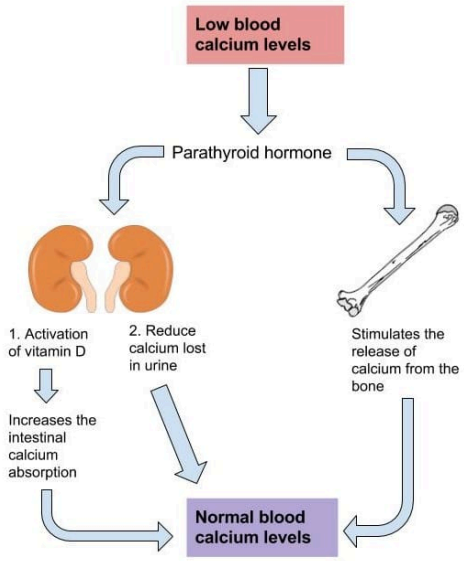


Figure 10.4.3.1: Maintaining Blood Calcium Levels. Image by Allison Calabrese / CC BY 4.0

Other Health Benefits of Calcium in the Body

Besides forming and maintaining strong bones and teeth, calcium has been shown to have other health benefits for the body, including:

- **Cancer**. The National Cancer Institute reports that there is enough scientific evidence to conclude that higher intakes of calcium decrease colon cancer risk and may suppress the growth of polyps that often precipitate cancer. Although higher calcium consumption protects against colon cancer, some studies have looked at the relationship between calcium and prostate cancer and found higher intakes may increase the risk for prostate cancer; however the data is inconsistent and more studies are needed to confirm any negative association.
- **Blood pressure**. Multiple studies provide clear evidence that higher calcium consumption reduces blood pressure. A review of twenty-three observational studies concluded that for every 100 milligrams of calcium consumed daily, systolic blood pressure is reduced 0.34 millimeters of mercury (mmHg) and diastolic blood pressure is decreased by 0.15 mmHg.[1]
- **Cardiovascular health**. There is emerging evidence that higher calcium intakes prevent against other risk factors for cardiovascular disease, such as high cholesterol and obesity, but the scientific evidence is weak or inconclusive.
- **Kidney stones**. Another health benefit of a high-calcium diet is that it blocks kidney stone formation. Calcium inhibits the absorption of oxalate, a chemical in plants such as parsley and spinach, which is associated with an increased risk for developing kidney stones. Calcium's protective effects on kidney stone formation occur only when you obtain calcium from dietary sources. Calcium supplements may actually increase the risk for kidney stones in susceptible people.



Figure 10.4.3.2: Calcium's Effect on Aging. Image by James Heilman, MD / CC BY-SA 3.0

Calcium inadequacy is most prevalent in adolescent girls and the elderly. Proper dietary intake of calcium is critical for proper bone health.

Despite the wealth of evidence supporting the many health benefits of calcium (particularly bone health), the average American diet falls short of achieving the recommended dietary intakes of calcium. In fact, in females older than nine years of age, the average daily intake of calcium is only about 70 percent of the recommended intake. Here we will take a closer look at particular groups of people who may require extra calcium intake.

- **Adolescent teens**. A calcium-deficient diet is common in teenage girls as their dairy consumption often considerably drops during adolescence.
- **Amenorrheic women and the "female athlete triad"**. Amenorrhea refers to the absence of a menstrual cycle. Women who fail to menstruate suffer from reduced estrogen levels, which can disrupt and have a negative impact on the calcium balance in their bodies. The "female athlete triad" is a combination of three conditions characterized by amenorrhea, disrupted eating patterns, and osteoporosis. Exercise-induced amenorrhea and anorexia nervosa-related amenorrhea can decrease bone mass.[2][3] In female athletes, as well as active women in the military, low BMD, menstrual irregularities, and individual dietary habits together with a history of previous stress issues are related to an increased susceptibility to future stress fractures.[4][5]
- **The elderly**. As people age, calcium bioavailability is reduced, the kidneys lose their capacity to convert vitamin D to its most active form, the kidneys are no longer efficient in retaining calcium, the skin is less effective at synthesizing vitamin D, there are changes in overall dietary patterns, and older people tend to get less exposure to sunlight. Thus the risk for calcium inadequacy is great.[6]
- **Postmenopausal women**. Estrogen enhances calcium absorption. The decline in this hormone during and after menopause puts postmenopausal women especially at risk for calcium deficiency. Decreases in estrogen production are responsible for an increase in bone resorption and a decrease in calcium absorption. During the first years of menopause, annual decreases in bone mass range from 3–5 percent. After age sixty-five, decreases are typically less than 1 percent.[7]
- **Lactose-intolerant people**. Groups of people, such as those who are lactose intolerant, or who adhere to diets that avoid dairy products, may not have an adequate calcium intake.
- **Vegans**. Vegans typically absorb reduced amounts of calcium because their diets favor plant-based foods that contain oxalates and phytates.[8]

In addition, because vegans avoid dairy products, their overall consumption of calcium-rich foods may be less.

If you are lactose intolerant, have a milk allergy, are a vegan, or you simply do not like dairy products, remember that there are many plant-based foods that have a good amount of calcium and there are also some low-lactose and lactose-free dairy products on the market.

Considerations for Transgender and Gender-diverse Individuals

Because sex-based DRIs differ for calcium, the clinician must interpret those in light of menstrual status, hormone therapy, and individual variation. On the biochemical and clinical lab side, evaluators should include bone mineral density (BMD) via DEXA, given risk of bone loss, particularly in gonad suppression phases.

Gender-affirming nutrition care demands flexibility: selecting or blending reference values based on hormonal state, tracking body composition changes rather than overreliance on rigid cutoffs, and anchoring nutrient recommendations in individualized lab data. Because the evidence base remains limited, ongoing data collection, research, and shared decision-making with clients are foundational to advancing best practice in this domain (Sousa et al., 2024; Gold et al., 2024). Calcium and vitamin D supplementation, alongside weight-bearing exercise, is essential for optimizing bone health in transgender and gender-diverse individuals (Gold, 2024).

Calcium Supplements: Which One to Buy?

Many people choose to fulfill their daily calcium requirements by taking calcium supplements. Calcium supplements are sold primarily as calcium carbonate, calcium citrate, calcium lactate, and calcium phosphate, with elemental calcium contents of about 200 milligrams per pill. It is important to note that calcium carbonate requires an acidic environment in the stomach to be used effectively. Although this is not a problem for most people, it may be for those on medication to reduce stomach-acid production or for the elderly who may have a reduced ability to secrete acid in the stomach. For these people, calcium citrate may be a better choice. Otherwise, calcium carbonate is the cheapest. The body is capable of absorbing approximately 30 percent of the calcium from these forms.

Beware of Lead

There is public health concern about the lead content of some brands of calcium supplements, as supplements derived from natural sources such as oyster shell, bone meal, and dolomite (a type of rock containing calcium magnesium carbonate) are known to contain high amounts of lead. In one study conducted on twenty-two brands of calcium supplements, it was proven that eight of the brands exceeded the acceptable limit for lead content. This was found to be the case in supplements derived from oyster shell and refined calcium carbonate. The same study also found that brands claiming to be lead-free did, in fact, show very low lead levels. Because lead levels in supplements are not disclosed on labels, it is important to know that products not derived from oyster shell or other natural substances are generally low in lead content. In addition, it was also found that one brand did not disintegrate as is necessary for absorption, and one brand contained only 77 percent of the stated calcium content.[9]

Diet, Supplements, and Chelated Supplements

In general, calcium supplements are less effective than dietary sources of calcium in delivering many of the health benefits associated with higher calcium intake. This is largely because whole foods provide additional nutrients that work synergistically to support health. While chelated forms of calcium supplements may offer slightly improved absorption — by shielding calcium from compounds like oxalates and phytates that interfere with uptake — the benefit is modest, increasing absorption by only about 10%, and these supplements tend to be more expensive.

Importantly, calcium supplementation alone offers limited benefits for bone health, especially in individuals with low dietary calcium intake. However, when taken alongside vitamin D, the benefits are much clearer: peak bone mass increases in early adulthood, bone mineral density (BMD) is better maintained over time, the risk of osteoporosis decreases, and fracture rates are reduced in those already diagnosed with the condition. It's not necessary to take calcium and vitamin D at the same time, but vitamin D must be active and present in the bloodstream to facilitate calcium absorption, making consistent intake of vitamin D essential.

Magnesium is another critical nutrient that should be included in a bone health supplement. It is an essential cofactor for the enzymes in the liver and kidneys that convert vitamin D into its active form, calcitriol. Additionally, it helps regulate calcium transport and metabolism. Without adequate magnesium, both vitamin D and calcium may be less effective, and long-term imbalances can even lead to calcification in soft tissues. Thus, a supplement containing calcium, vitamin D, and magnesium offers more comprehensive support for bone health than calcium and vitamin D alone.

Additionally, when it comes to calcium supplementation, less is more. The body can absorb only about 500–600 mg of calcium at a time, and absorption efficiency actually declines with higher doses. Thus, splitting calcium into smaller doses taken twice daily (e.g., 250–500 mg per dose) can improve absorption and overall calcium utilization. This approach improves calcium bioavailability and minimizes waste, while also reducing the risk of side effects such as bloating or constipation associated with higher doses.

The Calcium Supplement Debate

A recent study published in the British Medical Journal reported that people who take calcium supplements at doses equal to or greater than 500 milligrams per day in the absence of a vitamin D supplement had a 30 percent greater risk for having a heart attack.[10]

Does this mean that calcium supplements are bad for you? If you look more closely at the study, you will find that 5.8 percent of people (143 people) who took calcium supplements had a heart attack, but so did 5.5 percent of the people (111) people who took the placebo. While this is one study, several other large studies have not shown that calcium supplementation increases the risk for cardiovascular disease. While the debate over this continues in the realm of science, we should focus on the things we do know:

1. There is overwhelming evidence that diets sufficient in calcium prevent osteoporosis and cardiovascular disease.
2. People with risk factors for osteoporosis are advised to take calcium supplements if they are unable to get enough calcium in their diet. The National Osteoporosis Foundation advises that adults age fifty and above consume 1,200 milligrams of calcium per day. This includes calcium both from dietary sources and supplements.
3. Consuming more calcium than is recommended is not better for your health and can prove to be detrimental. Consuming too much calcium at any one time, be it from diet or supplements, impairs not only the absorption of calcium itself, but also the absorption of other essential minerals, such as iron and zinc. Because the GI tract can only handle about 500 milligrams of calcium at one time, it is recommended to have split doses of calcium supplements rather than taking a few all at once to get the RDA of calcium.

Dietary Reference Intake for Calcium

The recommended dietary allowances (RDA) for calcium are listed in Table 10.1. The RDA is elevated to 1,300 milligrams per day during adolescence because this is the life stage with accelerated bone growth. Studies have shown that a higher intake of calcium during puberty increases the total amount of bone tissue that accumulates in a person. For women above age fifty and men older than seventy-one, the RDAs are also a bit higher for several reasons including that as we age, calcium absorption in the gut decreases, vitamin D3 activation is reduced, and maintaining adequate blood levels of calcium is important to prevent an acceleration of bone tissue loss (especially during menopause). Currently, the dietary intake of calcium for females above age nine is, on average, below the RDA for calcium. The Institute of Medicine (IOM) recommends that people do not consume over 2,500 milligrams per day of calcium as it may cause adverse effects in some people.

Table 10.4.3.1: Dietary Reference Intakes for Calcium

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	200*	–
Infants (6–12 months)	260*	–
Children (1–3 years)	700	2,500
Children (4–8 years)	1,000	2,500
Children (9–13 years)	1,300	2,500
Adolescents (14–18 years)	1,300	2,500
Adults (19–50 years)	1,000	2,500
Adult females (50–71 years)	1,200	2,500
Adults, male & female (> 71 years)	1,200	2,500

Age Group	RDA (mg/day)	UL (mg/day)
* denotes Adequate Intake		

Source: Ross AC, Manson JE, et al. The 2011 Report on Dietary Reference Intakes for Calcium and Vitamin D from the Institute of Medicine: What Clinicians Need to Know. J Clin Endocrinol Metab. 2011; 96(1), 53–8. http://www.ncbi.nlm.nih.gov/pubmed/21118827. Accessed October 10, 2017.

Dietary Sources of Calcium

In the typical American diet, calcium is obtained mostly from dairy products, primarily cheese. A slice of cheddar or Swiss cheese contains just over 200 milligrams of calcium. One cup of nonfat milk contains approximately 300 milligrams of calcium, which is about a third of the RDA for calcium for most adults. Foods fortified with calcium such as cereals, soy milk, and orange juice also provide one third or greater of the calcium RDA. Although the typical American diet relies mostly on dairy products for obtaining calcium, there are other good non-dairy sources of calcium.

Tools for Change

If you need to increase calcium intake, are a vegan, or have a food allergy to dairy products, it is helpful to know that there are some plant-based foods that are high in calcium. Tofu (made with calcium sulfate), turnip greens, mustard greens, and chinese cabbage are good sources. For a list of non-dairy sources you can find the calcium content for thousands of foods by visiting the USDA National Nutrient Database (http://www.nal.usda.gov/fnic/foodcomp/search/). When obtaining your calcium from a vegan diet, it is important to know that some plant-based foods significantly impair the absorption of calcium. These include spinach, Swiss chard, rhubarb, beets, cashews, and peanuts. With careful planning and good selections, you can ensure that you are getting enough calcium in your diet even if you do not drink milk or consume other dairy products.

Calcium Bioavailability

In the small intestine, calcium absorption primarily takes place in the duodenum (first section of the small intestine) when intakes are low, but calcium is also absorbed passively in the jejunum and ileum (second and third sections of the small intestine), especially when intakes are higher. The body doesn't completely absorb all the calcium in food. Interestingly, the calcium in some vegetables such as kale, brussel sprouts, and bok choy is better absorbed by the body than are dairy products. About 30 percent of calcium is absorbed from milk and other dairy products.

The greatest positive influence on calcium absorption comes from having an adequate intake of vitamin D. People deficient in vitamin D absorb less than 15 percent of calcium from the foods they eat. The hormone estrogen is another factor that enhances calcium bioavailability. Thus, as a woman ages and goes through menopause, during which estrogen levels fall, the amount of calcium absorbed decreases and the risk for bone disease increases. Some fibers, such as inulin, found in jicama, onions, and garlic, also promote calcium intestinal uptake.

Chemicals that bind to calcium decrease its bioavailability. These negative effectors of calcium absorption include the oxalates in certain plants, the tannins in tea, phytates in nuts, seeds, and grains, and some fibers. Oxalates are found in high concentrations in spinach, parsley, cocoa, and beets. In general, the calcium bioavailability is inversely correlated to the oxalate content in foods. High-fiber, low-fat diets also decrease the amount of calcium absorbed, an effect likely related to how fiber and fat influence the amount of time food stays in the gut. Anything that causes diarrhea, including sickness, medications, and certain symptoms related to old age, decreases the transit time of calcium in the gut and therefore decreases calcium absorption. As we get older, stomach acidity sometimes decreases, diarrhea occurs more often, kidney function is impaired, and vitamin D absorption and activation is compromised, all of which contribute to a decrease in calcium bioavailability.

Table 10.4.3.2*: Calcium Content and Bioavailability of Various Foods*

Food	Serving	Calcium (mg)	Absorption (%)	Estimated Calcium Absorbed (mg)	% Daily Value1	% Daily Value2
Yogurt, low fat	8.5 oz.	300	32	96	7.4	9.6

Food	Serving	Calcium (mg)	Absorption (%)	Estimated Calcium Absorbed (mg)	% Daily Value1	% Daily Value2
Mozzarella, part skim	1.5 oz.	333	32	107	8.2	10.7
Sardines, canned with bones	3 oz.	325	27	88	6.8	8.8
Cheddar Cheese	1.5 oz.	303	32	97	7.5	9.7
Milk, nonfat	8.5 oz.	300	32	96	7.4	9.6
Soymilk, calcium fortified	8.5 oz.	300	24	72	5.5	7.2
Orange juice, calcium fortified	8.5 oz.	300	36	109	8.4	10.9
Tofu, firm, made with calcium sulfate	½ c.	258	31	80	6.2	8.0
Salmon, canned with bones	3 oz.	181	27	49	3.8	4.9
Turnip Greens	½ c.	99	52	51	4.0	5.1
Kale, cooked	1 c.	94	49	30	2.3	3.0
Vanilla Ice Cream, light	½ c.	84	32	27	2.1	2.7
Broccoli, cooked	1 c.	35	61	19	1.5	1.9
Cauliflower, cooked	1 c.	10	69	6.9	0.5	0.7
Red Beans, cooked	1 c.	41	24	9.84	0.8	1.0

[1]Based on DV = 1000 mg

[2]Based on DV = 1300 mg

Source: Office of Dietary Supplements. (2020, March 26). Calcium. https://ods.od.nih.gov/factsheets/Ca...hProfessional/ and Titchenal, C. A., & Dobbs, J. (2007). A system to assess the quality of food sources of calcium. Journal of Food Composition and Analysis, 20(8), 717–724. doi: 10.1016/j.jfca.2006.04.013

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10.4.4: Magnesium

Magnesium

Approximately 60% of magnesium in the human body is stored in the skeleton, making up about 1% of mineralized bone tissue. In addition to contributing to bone maintenance, magnesium has several other functions in the body. It is required in every reaction involving ATP, amounting to more than three hundred enzymatic reactions. Magnesium plays a role in the synthesis of DNA and RNA, carbohydrates, and lipids, and it's essential for nerve conduction, muscle contraction, and normal heart rhythm.

Magnesium's Functional Role

In its role in mineralized bone tissue, magnesium is not an integral part of the hard mineral crystals, but it does reside on the surface of the crystal and helps maximize bone structure. Observational studies link magnesium deficiency with an increased risk for osteoporosis.

Magnesium also works to regulate calcium in the body. Magnesium is a cofactor for the enzymes that activate vitamin D in the liver and kidneys, converting it into its usable, active form. Without enough magnesium, vitamin D remains in a stored, inactive state. A magnesium-deficient diet is associated with decreased levels of parathyroid hormone and the activation of vitamin D, which may lead to an impairment of bone remodeling. A study in nine hundred elderly women and men did show that higher dietary intakes of magnesium correlated to an increased BMD in the hip.[1] Only a few clinical trials have evaluated the effects of magnesium supplements on bone health and their results suggest some modest benefits on BMD.

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

Magnesium Deficiency and Toxicity

Most people in the U.S. do not reach the RDA for magnesium from their diets, and a low intake of green, leafy vegetables is a contributing factor, along with inadequate intake of other magnesium-rich foods like nuts, seeds, and whole grains. Some observational studies indicate that consuming adequate magnesium may improve health. For example, people with higher dietary intakes of magnesium tend to have lower rates of cardiovascular disease, type 2 diabetes, and osteoporosis, leading some researchers to hypothesize that low intake of magnesium may increase the risk of these chronic diseases. More studies are needed to determine whether magnesium supplements may help prevent these diseases. However, since magnesium is present in many healthful whole foods, improving magnesium intake through diet may bring multiple benefits.

Obvious magnesium deficiency due to low dietary intake is rare in healthy people, because the kidneys can decrease urinary excretion of this mineral when intake is inadequate. People at greater risk of magnesium deficiency include those with type 2 diabetes, gastrointestinal diseases like Crohn's and celiac, chronic alcoholism, and older adults. A magnesium deficiency can cause decreased appetite, nausea, vomiting, fatigue, and weakness. If extreme, it can cause personality changes, muscle cramps, numbness, tingling, seizures, and an abnormal heart rhythm.[3]

Excessive intake of magnesium from foods is not a risk, as the kidneys can effectively excrete it if it's in excess. However, people should take care not to consume more than the UL for magnesium from supplements and medications.[3]

Dietary Reference Intakes for Magnesium

The RDAs for magnesium for adults between ages nineteen and thirty are 400 milligrams per day for males and 310 milligrams per day for females. For adults above age thirty, the RDA increases slightly to 420 milligrams per day for males and 320 milligrams for females.

Table 10.4.4.1: *Dietary Reference Intakes for Magnesium*

Age Group	RDA (mg/day)	UL from non-food sources (mg/day)
Infants (0–6 months)	30*	–
Infants (6–12 months)	75*	–
Children (1–3 years)	80	65
Children (4–8 years)	130	110
Children (9–13 years)	240	350
Adolescents (14–18 years)	410	350
Adults (19–30 years)	400	350
Adults (> 30 years)	420	350
* denotes Adequate Intake		

Source: Dietary Supplement Fact Sheet: Magnesium. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/Magnesium-HealthProfessional/. Updated July 13, 2009. Accessed November 12, 2017.



Dietary Sources of Magnesium

Magnesium is part of the green pigment, chlorophyll, which is vital for photosynthesis in plants; therefore green leafy vegetables are good dietary sources of magnesium. Magnesium is also found in high concentrations in nuts, whole grains, legumes, potatoes, dairy products, fish, and meats. Most foods that are high in fiber are good sources of magnesium, and it is added to some fortified foods, such as breakfast cereal. Additionally, chocolate, coffee, and hard water contain a good amount of magnesium.

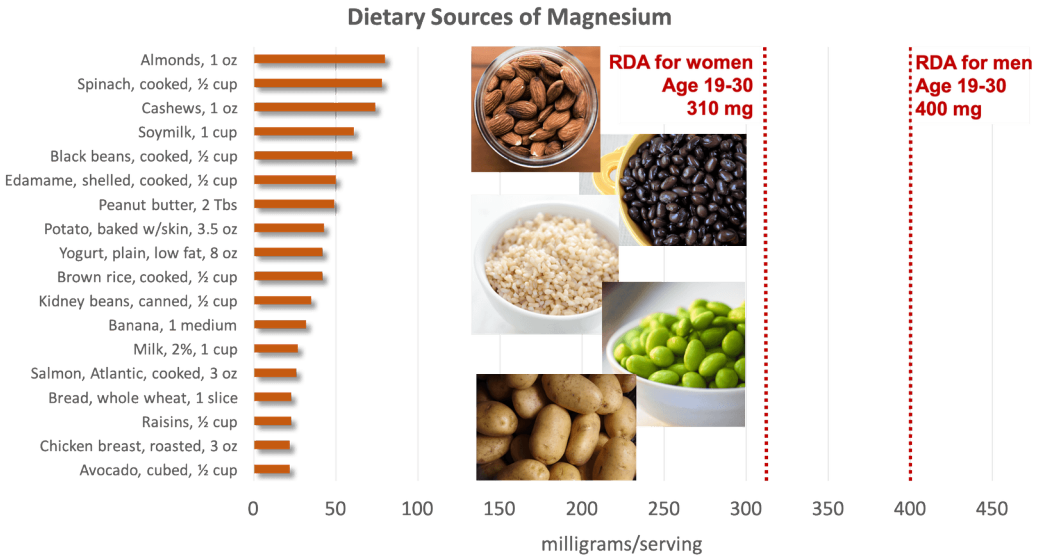


Figure 10.4.4.2: Dietary sources of magnesium. Examples of good sources pictured include almonds, black beans, brown rice, edamame, and potatoes. Source: *NIH Office of Dietary Supplements*(Copyright; author via source)

Table 10.4.4.2: Magnesium Content of Various Foods

Food	Serving	Magnesium (mg)	Percent Daily Value
Almonds	1 oz.	80	20
Cashews	1 oz.	74	19
Soymilk	1 c.	61	15
Black beans	½ c.	60	15
Edamame	½ c.	50	13
Bread	2 slices	46	12
Avocado	1 c.	44	11
Brown rice	½ c.	42	11
Yogurt	8 oz.	42	11
Oatmeal, instant	1 packet	36	9
Salmon	3 oz.	26	7
Chicken breasts	3 oz.	22	6
Apple	1 medium	9	2

Source: Dietary Supplement Fact Sheet: Magnesium. National Institutes of Health, Office of Dietary Supplements. http://ods.od.nih.gov/factsheets/Magnesium-HealthProfessional/. Updated July 13, 2009. Accessed November 12, 2017.

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10.4.5: Phosphorus

Phosphorus

Phosphorus is the second most abundant mineral in the human body, and 85% of the body's phosphorus is housed in the skeleton.

Phosphorus's Functional Role

Phosphorus is present in our bodies as part of a chemical group called a phosphate group. These phosphate groups are essential as a structural component of cell membranes (as phospholipids), DNA and RNA, energy production (ATP), and regulation of acid-base homeostasis. In addition, phosphate also plays important roles in regulating cell signaling, and enzyme activity, as well as being part of creatine phosphate, which is an energy source for muscles during exercise.[1]

Phosphorus is mostly associated with calcium as a part of the mineral structure of bones and teeth. Because phosphorus is present with calcium in mineralized bone, it is somewhat regulated in parallel to calcium. PTH and activated vitamin D stimulate bone resorption, increasing not only blood 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.

Phosphorus Deficiency and Toxicity

Both deficiency and toxicity of phosphorus are rare. The average intake of phosphorus in U.S. adults ranges between 1,000 and 1,500 milligrams per day, well above the RDA of 700 milligrams per day. The UL set for phosphorus is 4,000 milligrams per day for adults and 3,000 milligrams per day for people over age 70. Very high doses of phosphorus taken in supplement form can interfere with calcium regulation and cause calcification, or hardening, of soft tissues, especially the kidneys.[2]

Emerging research has linked excessive phosphorus intake — particularly from inorganic additives found in processed foods and soft drinks — to increased risk of all-cause mortality. A growing body of epidemiological evidence suggests that high serum phosphate levels, often resulting from diets rich in phosphate additives, are associated with vascular calcification, kidney dysfunction, and cardiovascular disease, all of which contribute to higher mortality rates.[3,4]

Phosphoric acid, commonly used in colas and other soft drinks, is a highly absorbable form of inorganic phosphorus that bypasses the body's regulatory mechanisms, leading to spikes in serum phosphate. In contrast, the organic phosphorus naturally present in milk and other dairy foods is bound within proteins and requires enzymatic digestion, resulting in slower absorption and more controlled phosphate levels. This distinction in bioavailability helps explain why phosphorus from whole foods like dairy is generally not associated with the same adverse health risks as phosphorus from additives.

Dietary Reference Intakes for Phosphorus

In contrast to calcium, most Americans are not at risk for having a phosphate deficiency. Phosphate is present in many foods popular in the American diet including meat, fish, dairy products, processed foods, and beverages. Phosphate is added to many foods because it acts as an emulsifying agent, prevents clumping, improves texture and taste, and extends shelf-life.

Table 10.4.5.1*: Dietary Reference Intakes for Phosphorus*

Age Group	RDA (mg/day)	UL (mg/day)
Infants (0–6 months)	100*	–
Infants (6–12 months)	275*	–
Children (1–3 years)	460	3,000

Age Group	RDA (mg/day)	UL (mg/day)
Children (4–8 years)	500	3,000
Children (9–13 years)	1,250	4,000
Adolescents (14–18 years)	1,250	4,000
Adults (19–70 years)	700	4,000
Adults (> 70 years)	700	3,000
* denotes Adequate Intake		

Micronutrient Information Center: Phosphorus. Oregon State University, Linus Pauling Institute. http://lpi.oregonstate.edu/mic/minerals/phosphorus. Updated in July 2013. Accessed October 22, 2017.

Dietary Sources of Phosphorus

In comparison to calcium, most people in the U.S. are not at risk for inadequate intake of phosphorus. Phosphorus is present in many foods, including meat, fish, dairy products, potatoes, nuts, beans, and whole grains. Phosphorus is also added to soft drinks and many processed foods, because it acts as an emulsifying agent, prevents clumping, improves texture and taste, and extends shelf life.

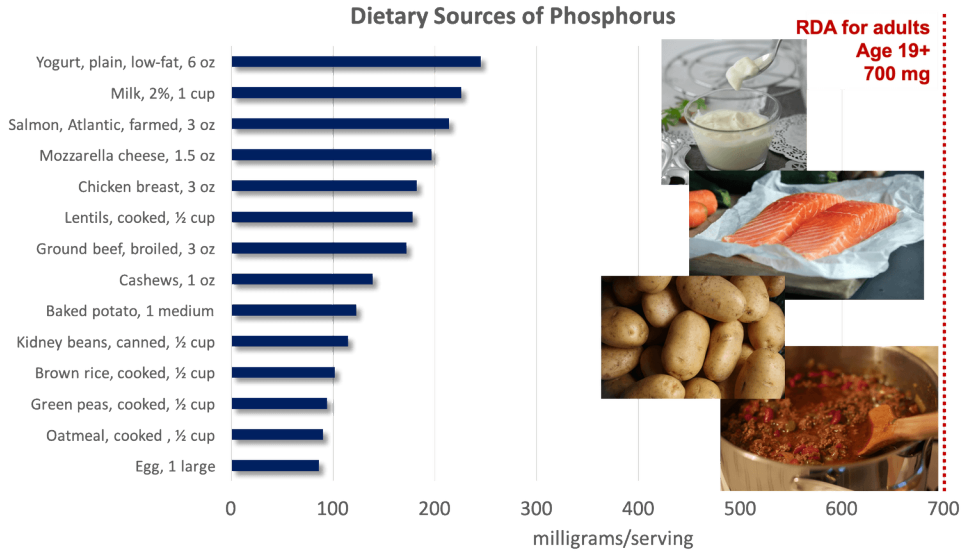


Figure 10.4.5.1: Food sources of phosphorus. Examples of good sources pictured include yogurt, salmon, potatoes, and chili (made with ground beef and kidney beans). Source: NIH *Office of Dietary Supplements* (Copyright; author via source)

Table 10.4.5.2: Phosphorus Content of Various Foods

Foods	Serving	Phosphorus (mg)	Percent Daily Value 1000
Salmon	3 oz.	315	32
Yogurt, nonfat	8 oz.	306	31
Turkey, light meat	3 oz.	217	22
Chicken, light meat	3 oz.	135	14
Beef	3 oz.	179	18

Foods	Serving	Phosphorus (mg)	Percent Daily Value 1000
Lentils*	½ c.	178	18
Almonds*	1 oz.	136	14
Mozzarella	1 oz.	131	13
Peanuts*	1 oz.	108	11
Whole wheat bread	1 slice	68	7
Egg	1 large	86	9
Carbonated cola drink	12 oz.	41	4
Bread, enriched	1 slice	25	3

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10.4.6: Fluoride

Fluoride's Functional Role

Fluoride is a trace mineral needed in very small amounts in the body. It is known mostly as the mineral that combats tooth decay, but it also plays a role in assisting with tooth and bone development and maintenance. Because it isn't necessary for growth or to sustain life, fluoride is generally not considered an essential mineral. However, fluoride's role in preventing dental caries (i.e., tooth decay), the most prevalent chronic disease in children and adults, underscores the importance of this mineral in the human diet.[4]

Fluoride combats tooth decay via three mechanisms:

- Blocking acid formation by bacteria
- Preventing demineralization of teeth
- Enhancing remineralization of destroyed enamel

Fluoride

As a natural mineral, fluoride is present in the soil and water in varying concentrations depending on geographical location. In the 1930s, researchers observed that children living in areas with naturally higher fluoride concentrations in their drinking water had a lower incidence of cavities, leading to the idea that adding fluoride to municipal water supplies could benefit public health. Fluoride was first added to drinking water in 1945 in Grand Rapids, Michigan; now over 60 percent of the U.S. population consumes drinking water that has been supplemented with fluoride to provide amounts that support dental health. The Centers for Disease Control and Prevention (CDC) has reported that fluoridation of water reduces cavities by 25 percent in children and adults and considers water fluoridation one of the ten great public health achievements in the twentieth century.[5]

Fluoride's benefits to mineralized tissues of the teeth are well substantiated, but fluoride also plays an important role in the mineralization of bones, increasing their structural stability. Fluoride is currently being researched as a potential treatment for osteoporosis. The data are inconsistent on whether consuming fluoridated water reduces the incidence of osteoporosis and fracture risk. Fluoride does stimulate osteoblast bone building activity, and fluoride therapy in patients with osteoporosis has been shown to increase bone mineral density. In general, it appears that at low doses, fluoride treatment increases bone mineral density in people with osteoporosis and is more effective in increasing bone quality when the intakes of calcium and vitamin D are adequate. The Food and Drug Administration has not approved fluoride for the treatment of osteoporosis, mainly because its benefits are not sufficiently known. It also has several side effects, including frequent stomach upset and joint pain. The doses of fluoride used to treat osteoporosis are much greater than that in fluoridated water.

Dietary Sources of Fluoride

Fluoride is not widely found in the food supply. In communities with municipal water fluoridation, greater than 70 percent of fluoride intake comes from drinking water. In communities without fluoridated water, intake depends on how much fluoride occurs naturally in the water, but in most areas, natural levels fall below amounts recommended for cavity prevention. Other beverages with a high amount of fluoride include teas and grape juice. Solid foods do not generally contain a large amount of fluoride, although this depends on the fluoride level of the soil and water it was grown in and whether it was cooked with fluoridated water. Canned meats and fish that contain bones do contain some fluoride. Other good non-dietary sources are fluoridated toothpaste and dental rinses.



Figure 9.9. Dietary sources of fluoride include water, tea, shellfish, and fluoridated dental products such as toothpaste.

Table 10.4.6.2*: Fluoride Content of Various Foods*

Food	Serving	Fluoride (mg)	Percent Daily Value*
Fruit Juice	3.5 fl oz.	0.02-2.1	0.7-70
Crab, canned	3.5 oz.	0.21	7
Rice, cooked	3.5 oz.	0.04	1.3
Fish, cooked	3.5 oz.	0.02	0.7
Chicken	3.5 oz.	0.015	0.5
* Current AI used to determine Percent Daily Value			

Micronutrient Information Center: Fluoride. Oregon State University, Linus Pauling Institute. lpi.oregonstate.edu/mic/minerals/fluoride . Updated in April 29, 2015. Accessed October 22, 2017.

Fluoride Deficiency and Toxicity

Because it is a nonessential mineral, there is no defined fluoride requirement, but lower levels are associated with higher rates of dental cavities in adults and children. This connection is why so many water supplies are fluoridated.

However, as with all minerals, fluoride can also be quite toxic if consumed in excessive amounts. Acute toxicity symptoms from large intakes of fluoride include nausea, vomiting, diarrhea, and convulsions. Chronic toxicity results in an irreversible condition known as ***fluorosis***, characterized by the mottling (i.e., white speckling) and pitting of the teeth (see Figure 9.10). Fluorosis is primarily a risk in children, because mineralization of permanent teeth has typically occurred by age 8.[6]



Figure 9.10. A mild case of fluorosis (left) vs. a severe case of fluorosis (right).

Because fluoridated oral care products often taste good, making them appealing to young children, it is important to make sure infants and children do not consume too much fluoride by swallowing toothpaste or other oral care products. Recommendations for managing fluoride intake in children include the following:[7-9]

- Do not use any fluoride supplement without talking to your health care provider.
- Consider a prescription fluoride supplement for children who live in communities without fluoridated water or rely on a well water supply that is not fluoridated.
- Use only a smear (rice-sized) amount of fluoride toothpaste as soon as the first tooth erupts in infants up through age 2

years.
- Use only a pea-sized amount of fluoride toothpaste in children ages 3 to 6 years.
- Encourage children to spit out toothpaste instead of swallowing it.
- Avoid fluoride mouth rinses in children younger than 6 years.

Fluoridated Water — Concerns and Evidence

While some have raised concerns about fluoridated water, decades of scientific review and public-health practice attest to its safety and effectiveness as a strategy to prevent dental caries. Major expert bodies in the U.S., U.K., Australia, and elsewhere have conducted systematic reviews concluding that community water fluoridation (CWF) at optimal levels (roughly 0.7–1.2 mg/L) reduces tooth decay by about 25–60% in children and adults, with minimal risk of adverse effects under those levels (Griffin et al., 2007; McLaren & Singhal, 2016; CDC, 2021).

An illuminating case comes from Israel: After fluoridation was made mandatory in 2002 and many children in fluoridated areas had significantly lower caries experience than those in non-fluoridated areas, CWF was discontinued in 2014. Subsequently, studies have found substantial increases in dental restorations and crowns among young children, especially in lower socioeconomic groups (Kaufman et al., 2024). Equity is a central issue: Those without routine access to dentists, daily dental care, or fluoride toothpaste rely heavily on fluoridated water as a population-level preventive measure. Removing or weakening fluoridation disproportionately harms these vulnerable groups.

There is a recent study in the U.S. (Malin et al., 2024) that found an association between maternal fluoride exposure during pregnancy and small increases in certain neurobehavioral problems in children at age three, even at fluoride exposure levels typical of fluoridated communities. While this raises a question for further research, it does not yet overturn the large body of evidence supporting fluoridation's safety when levels are kept within recommended limits. Ongoing studies, especially those that better characterize fluoride exposure (from all sources), critical windows of development, and long-term neurodevelopmental outcomes, are needed to address lingering concerns.

Table 10.4.6.1: Selected Studies on Water Fluoridation

Study	Topic	Findings	Citation
Griffin et al. (2007)	Effectiveness	Systematic review found 27% median reduction in tooth decay among children in fluoridated areas.	Griffin SO, et al. *J Dent Res.* 2007;86(5):410–5.
McLaren & Singhal (2016)	Equity	Water fluoridation reduced socioeconomic disparities in dental caries among Canadian children.	McLaren L, Singhal S. *J Public Health Dent.* 2016;76(4):307–15.
Kaufman et al. (2024)	Israel case study	Dental treatment needs rose significantly in young children after fluoridation stopped in Israel.	Kaufman N, et al. *Health Econ Rev.* 2024;14(1):8.
CDC (2021)	Safety	CDC affirms decades of evidence supporting the safety of community water fluoridation.	CDC Statement on Fluoridation, 2021. CDC.gov
Malin et al. (2024)	Neurodevelopment	Found associations between prenatal fluoride exposure and increased risk of certain behavioral problems in 3-year-olds.	Malin AJ, et al. *JAMA Netw Open.* 2024;7(6):e2414654.

Dietary Reference Intake

The IOM has given Adequate Intakes (AI) for fluoride, but has not yet developed RDAs. The AIs are based on the doses of fluoride shown to reduce the incidence of cavities, but not cause dental fluorosis. From infancy to adolescence, the AIs for fluoride increase from 0.01 milligrams per day for ages less than six months to 2 milligrams per day for those between the ages of fourteen and eighteen. In adulthood, the AI for males is 4 milligrams per day and for females is 3 milligrams per day. The UL for young children is set at 1.3 and 2.2 milligrams per day for girls and boys, respectively. For adults, the UL is set at 10 milligrams per day.

Table 10.4.6.1: *Dietary Reference Intakes for Fluoride*

Age Group	AI (mg/day)	UL (mg/day)
Infants (0–6 months)	0.01	0.7
Infants (6–12 months)	0.50	0.9
Children (1–3 years)	0.70	1.3
Children (4–8 years)	1.00	2.2
Children (9–13 years)	2.00	10.0
Adolescents (14–18 years)	3.00	10.0
Adult Males (> 19 years)	4.00	10.0
Adult Females (> 19 years)	3.00	10.0

Source: Institute of Medicine. (1997). *Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride*. . www.iom.edu/Reports/1997/Diet...-Fluoride.aspx.

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10.5: Minerals and Healthy Blood — Fe and Cu

Minerals and Healthy Blood — The role of Iron (Fe) and Copper (Cu)

Blood is essential to life. It transports absorbed nutrients and oxygen to cells, removes metabolic waste products for excretion, and carries molecules, such as hormones, to allow for communication between organs.

Blood is a connective tissue of the circulatory system, made up of four components forming a matrix:

- ***red blood cells*** (or erythrocytes), which transport oxygen to cells
- ***white blood cells*** (or leukocytes), which are part of the immune system and help destroy foreign invaders
- ***platelets,*** which are fragments of cells that circulate to assist in blood clotting
- ***plasma,*** which is the fluid portion of the blood and contains proteins that help transport nutrients (e.g., fat-soluble vitamins) and aid in blood clotting.

Minerals play a crucial role in maintaining healthy blood, and among the most important of these are the trace minerals, iron and copper.

Iron is essential for the production of hemoglobin, the protein in red blood cells that transports oxygen throughout the body. Without adequate iron, the body cannot produce enough healthy red blood cells, leading to conditions such as iron-deficiency anemia.

Copper, though needed in smaller amounts, is equally vital — it helps the body absorb and utilize iron and is involved in the formation of hemoglobin and red blood cells. This section focuses on iron and copper because of their direct impact on blood health, illustrating how these trace minerals have significant effects on overall physiological function.

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10.5.1: Iron

Iron

Iron is a trace mineral. It is a necessary component of many proteins in the body responsible for functions such as the transport of oxygen energy metabolism, immune function, and antioxidant defense. Iron is also important in brain development and function.

Iron is essential for oxygen transport because of its role in ***hemoglobin***, a protein in red blood cells that transports oxygen to cells and gives red blood cells their color. Hemoglobin is composed of four globular peptides, each with an iron-containing heme complex in the center (Figure 9.X).

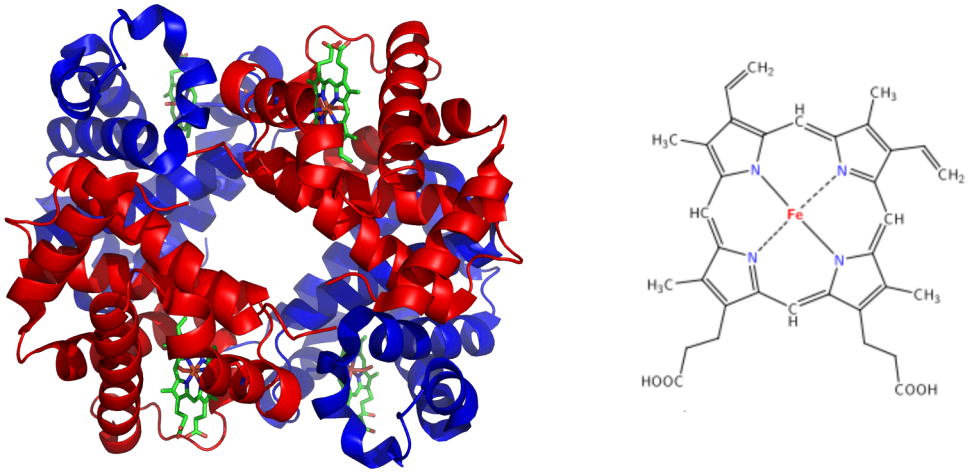


Figure 9.19. The structure of hemoglobin and the heme complex. On the left, the structure of hemoglobin includes four globular peptides (shown in blue and red) and the iron-containing heme groups (shown in green). On the right is a closer view of the heme complex.

The iron in hemoglobin is what binds to oxygen, allowing for transportation to cells. If iron levels are low, hemoglobin is not synthesized in sufficient amounts, and the oxygen-carrying capacity of red blood cells is reduced, resulting in ***anemia***. Iron is also an important part of ***myoglobin***, a protein similar to hemoglobin but found in muscles.

The majority of the body's iron is in red blood cells, which contain the oxygen-carrier protein hemoglobin. In the center of each heme, lies iron (Figure 11.2). Iron is needed for the production of other iron-containing proteins such as myoglobin. Myoglobin is a protein found in the muscle tissues that enhances the amount of available oxygen for muscle contraction. Iron is also a key component of hundreds of metabolic enzymes. Many of the proteins of the electron-transport chain contain iron–sulfur clusters involved in the transfer of high-energy electrons and ultimately ATP synthesis. Iron is also involved in numerous metabolic reactions that take place mainly in the liver and detoxify harmful substances. Moreover, iron is required for DNA synthesis. The great majority of iron used in the body is that recycled from the continuous breakdown of red blood cells.

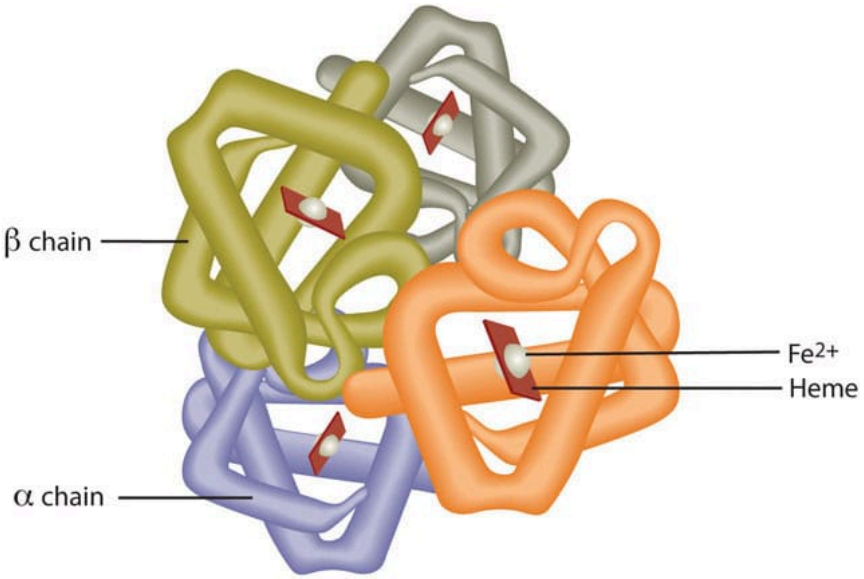


Figure 10.5.1.1: The Structure of Hemoglobin. Image by Allison Calabrese / CC BY 4.0

Hemoglobin is composed of four peptides. Each contains a heme group with iron in the center.

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

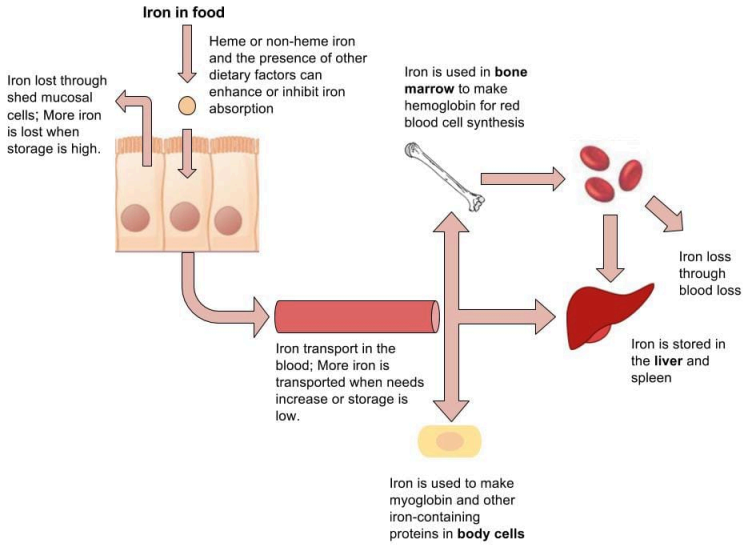


Figure 10.5.1.2: Iron Absorption, Functions, and Loss. Image by Allison Calabrese / CC BY 4.0

Dietary Sources of Iron

There are two types of iron found in foods:***heme iron*** and ***non-heme iron***.

- **Heme iron** is iron that is part of the proteins hemoglobin and myoglobin, so it is found only in foods of animal origin, such

as meat, poultry, and fish. Heme iron is the most bioavailable form of iron. About 40% of the iron in animal foods is heme iron and 60% is non-heme iron.

- **Non-heme iron** is the mineral by itself and is not a part of hemoglobin or myoglobin. Non-heme iron can be found in foods from both plants (e.g., nuts, beans, vegetables, and fortified and whole grains) and animals. It is less bioavailable than heme iron. Consuming vitamin C, meat, poultry, and seafood with non-heme iron increases its bioavailability. For example, eating an orange (a good source of vitamin C) along with your bowl of vegetarian chili will help you to absorb more of the iron from the beans and vegetables. On the other hand, chemicals such as phytates (found in beans and grains) and plant polyphenols (found in fruits, vegetables, some cereals, legumes, tea, coffee, and wine) decrease bioavailability due to binding with iron.[1]

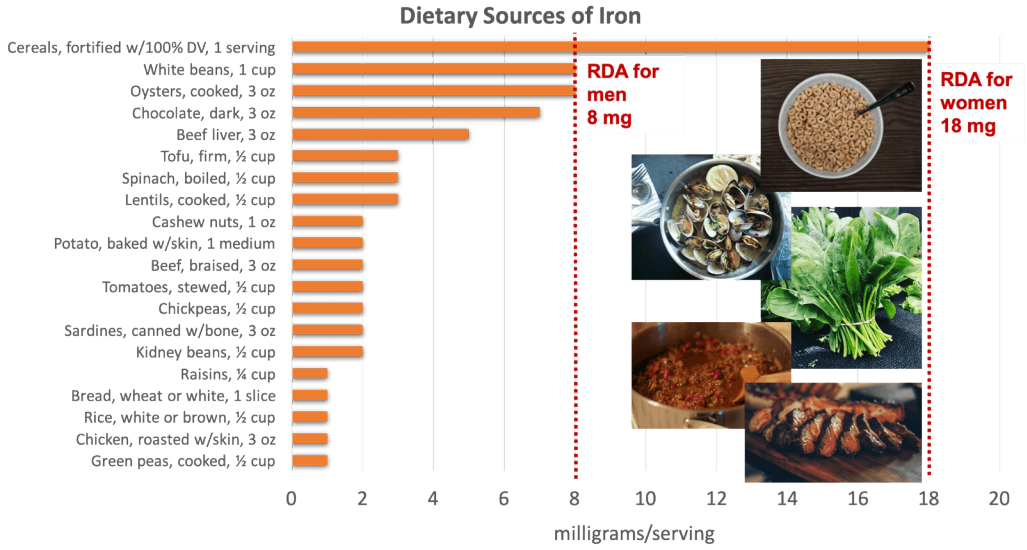


Figure 9.20. Dietary sources of iron. *Examples of good sources pictured include fortified cereal, clams, spinach, lentils and red meat. Source: NIH Office of Dietary Supplements*

The majority of the body's iron needs are not met by dietary sources, but rather by recycling iron within the body (***endogenous*** sources). Ninety percent of daily iron needs are met by recycling iron released from the breakdown of aging cells, mostly red blood cells.[2]

The body has no physiological mechanism to excrete iron; therefore, iron balance is tightly regulated by absorption.[2] When iron stores are low, more dietary iron will be absorbed.

The bioavailability of iron is highly dependent on dietary sources, as well as iron status. In animal-source foods, about 60 percent of iron is bound to hemoglobin, and heme iron is more bioavailable than nonheme iron. The other 40 percent of iron in animal-source foods is nonheme, which is the only iron source in plant-source foods. Some plant-source foods such as whole grains, tea, spinach, rhubarb, wine, and dark chocolate contain chemicals — phytate, oxalates, tannins, and polyphenols — that inhibit iron absorption.

For these reasons, bioavailability of iron is approximately 14% to 18% from mixed diets and 5% to 12% from vegetarian diets.[2] Vegetarians and vegans with high iron needs are at higher risk for iron deficiency, but careful meal planning with iron-rich plant-source foods and avoiding consumption of black tea two hours before or after a meal with iron-containing foods can prevent its development. There are also enhancers of iron absorption. For example, eating fruits and vegetables rich in vitamin C at the same time as iron-containing foods markedly increases iron absorption.

Table 10.5.1.1*: Enhancers and Inhibitors of Iron Absorption*

Enhancer	Inhibitor
Meat	Phosphate

Enhancer	Inhibitor
Fish	Calcium
Poultry	Tea
Seafood	Coffee
Stomach acid	Colas
Vitamin C	Soy protein
	High doses of minerals (antacids)
	Bran/fiber
	Phytates
	Oxalates
	Polyphenols

Iron Deficiency

Iron deficiency is one of the most common nutrient deficiencies worldwide — WHO estimates that 80 percent of people are iron deficient and 1/3 of the world's population has iron-deficiency anemia.[3] The main causes of iron deficiency worldwide are inadequate intake of animal-source foods, exacerbated by parasitic worm infections in the gut causing excessive blood loss, and malaria, a parasitic disease causing the destruction of red blood cells. In high-income countries, iron deficiency is more the result of dietary insufficiency and/or excessive blood loss occurring during menstruation, especially for vegetarians or vegans, or childbirth.

Iron-deficiency anemia is a condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells that contain less hemoglobin. As a result, blood carries less oxygen from the lungs to cells. Iron-deficiency anemia has the following signs and symptoms, which are linked to the essential functions of iron in energy metabolism and blood health:

- Fatigue
- Weakness
- Pale skin
- Shortness of breath
- Dizziness
- Swollen, sore tongue
- Abnormal heart rate

At-Risk Populations

Infants, children, adolescents, and women are the populations most at risk worldwide for iron-deficiency anemia.[4] Infants who are premature, low birthweight, or have a mother with iron deficiency are at risk for iron deficiency, because they are born with low iron stores relative to the amount needed for growth and development. Young children and adolescent girls are at risk for iron deficiency due to rapid growth, low dietary intake of iron, as well as heavy menstruation for adolescent girls. In these populations, iron-deficiency anemia can also cause the following signs and symptoms: ***pica*** (an intense craving for and ingestion of non-food items such as paper, dirt, or clay), poor growth, failure to thrive, and poor performance in school, as well as mental, motor, and behavioral disorders. Women who experience heavy menstrual bleeding, or who are pregnant, are also at risk for iron inadequacy due to their increased requirements for iron.

To give you a better understanding of these risks, it is helpful to look at how much higher the RDA is for women of reproductive age and pregnant women compared to men (Table 9.2).[1] To put this in perspective, 3 ounces of beef contains about 3 milligrams of iron, making it challenging for some women to meet their daily iron requirement.

Population Group	RDA for Iron
Women of reproductive age, 19-50 years	18 mg/day
Pregnancy, 19- 50 years	27 mg/day
Men, 19-50 years	8 mg/day

Table 9.2. A comparison of the RDAs for adult women of reproductive age, pregnancy, and adult men.

Additionally, those who frequently donate blood, as well as people with cancer, heart failure, or gastrointestinal diseases such as Crohn's, are at greater risk for iron inadequacy.[1]

Iron deficiency progresses through three stages:[1]

1. **Mild depletion of iron stores** – No physical symptoms will be present, because hemoglobin levels are not affected, but there will be a decrease in ***ferritin*** (a storage form of iron).
2. **Iron-deficient erythropoiesis** (erythrocyte or red blood cell production) – Iron stores are depleted and iron transport is decreased due to a decrease in ***transferrin*** (the transport protein for iron), but hemoglobin levels are usually within the normal range.
3. **Iron-deficiency anemia –** Iron stores are exhausted and hemoglobin levels are reduced, resulting in ***microcytic anemia*** (small red blood cells) and ***hypochromic anemia*** (low color red blood cells).

Preventing Iron-Deficiency Anemia

In young children iron-deficiency anemia can cause significant motor, mental, and behavioral abnormalities that are long-lasting. In the United States, the high incidence of iron-deficiency anemia in infants and children was a major public-health problem prior to the early 1970s, but now the incidence has been greatly reduced. This achievement was accomplished by implementing the screening of infants for iron-deficiency anemia in the health sector as a common practice, advocating the fortification of infant formulas and cereals with iron, and distributing them in supplemental food programs, such as that within Women, Infants, and Children (WIC). Breastfeeding, iron supplementation, and delaying the introduction of cow's milk for at least the first twelve months of life were also encouraged. These practices were implemented across the socioeconomic spectrum and by the 1980s iron-deficiency anemia in infants had significantly declined. Other solutions had to be introduced in young children, who no longer were fed breast milk or fortified formulas and were consuming cow's milk. The following solutions were introduced to parents: provide a diet rich in sources of iron and vitamin C, limit cow's milk consumption to less than twenty-four ounces per day, and a multivitamin containing iron.

In low-income countries, iron-deficiency anemia remains a significant public-health challenge. The World Bank claims that a million deaths occur every year from anemia and that the majority of those occur in Africa and Southeast Asia. The World Bank states five key interventions to combat anemia:[4]

- Provide at-risk groups with iron supplements.
- Fortify staple foods with iron and other micronutrients whose deficiencies are linked with anemia.
  - Support point-of-use (home) fortification strategies for older infants and young children
- Prevent the spread of malaria and treat the hundreds of millions with the disease.
- Provide insecticide-treated bed netting to prevent parasitic infections.
- Treat parasitic-worm infestations in high-risk populations.

Also, there is ongoing research into providing cast iron fish or iron cookware to at-risk populations is effective in preventing and treating iron-deficiency anemia.

Iron Toxicity

Healthy adults are at little risk of iron overload from foods, but too much iron from supplements can result in gastric upset, constipation, nausea, vomiting, and abdominal pain.[1] The body excretes little iron and therefore the potential for accumulation in tissues and organs is considerable. Iron accumulation in certain tissues and organs can cause a host of health problems in children and adults including extreme fatigue, arthritis, joint pain, and severe liver and heart toxicity.

Mostly a hereditary disease, hemochromatosis is the result of a genetic mutation that leads to abnormal iron metabolism and an accumulation of iron in certain tissues such as the liver, pancreas, and heart. The signs and symptoms of hemochromatosis are similar to those of iron overload in tissues caused by high dietary intake of iron or other non-genetic metabolic abnormalities, but are often increased in severity.

The potential for toxicity from supplements is high. Accidental ingestion of iron-containing supplements is a leading cause of poisoning-related death in young children. Due to their candy-like appearance and high iron content, even a small number of tablets can cause severe toxicity, leading to symptoms such as vomiting, metabolic acidosis, and multi-organ failure if not promptly treated. Death has occurred in children from ingesting as little as 200 mg of iron, so it is critical to keep iron supplements out of children's reach. The tolerable upper intake for iron is 45 mg per day for adults, based on the amount that causes gastrointestinal distress.[1]

Dietary Reference Intakes for Iron

Table 10.5.1.2: Dietary Reference Intakes for Iron

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

Dietary Sources of Iron

Table 10.5.1.3: Iron Content of Various Foods

Food	Serving	Iron (mg)	Percent Daily Value
Breakfast cereals, fortified	1 serving	18	100
Oysters	3 oz.	8	44
Dark chocolate	3 oz.	7	39
Beef liver	3 oz.	5	28
Lentils	½ c.	3	17

Food	Serving	Iron (mg)	Percent Daily Value
Spinach, boiled	½ c.	3	17
Tofu, firm	½ c.	3	17
Kidney beans	½ c.	2	11
Sardines	3 oz.	2	11

Considerations for Transgender and Gender-diverse Individuals

Because sex-based DRIs differ for iron, clinicians may find it helpful to interpret these values in the context of menstrual status, hormone therapy, and individual variation. For individuals who are pregnant, the pregnancy-specific DRI for iron can provide useful guidance. Those who are menstruating might reference the DRI established for adolescent girls or women of reproductive age, which reflects the higher iron losses associated with menstruation. For individuals who do not menstruate or who no longer menstruate, considering the age-appropriate DRI for males or for women aged 51 years and older may be reasonable, given their typically lower iron requirements. On the biochemical and clinical laboratory side, including measurements such as hemoglobin and hematocrit (to assess anemia or bleeding risk) and ferritin (to evaluate iron stores) can offer additional insight into iron status.

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- Table 9.2. “A comparison of the RDAs” by Tamberly Powell is licensed under CC BY 4.0 with data from National Institutes of Health of Dietary Supplements. *Iron – Health Professional Fact Sheet*. Retrieved April 29, 2020 from https://ods.od.nih.gov/factsheets/Iron-HealthProfessional/#en4
- Figure 9.19. “Dietary sources of iron” by Alice Callahan is licensed under CC BY 4.0, with images: Breakfast cereal by John Matychuk, clams by Adrien Sala, spinach by Elianna Friedman, steak by Emerson Vieira on Unsplash (license information); “Superbowl Chili” by Jake Przespo is licensed under CC BY 2.0.

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10.5.2: Copper

Copper

Copper is an essential trace mineral that plays a vital role in maintaining healthy blood and overall hematologic function. It is a key component of several enzymes involved in iron metabolism, including ceruloplasmin, which facilitates the transport of iron from storage sites into the bloodstream. Without adequate copper, iron cannot be efficiently mobilized or incorporated into hemoglobin, the oxygen-carrying protein in red blood cells. As a result, copper deficiency can lead to anemia, even in the presence of sufficient iron levels. This section explores the mechanisms by which copper supports blood health, the consequences of copper imbalance, and dietary sources that help maintain optimal copper status.

Functional Roles

Copper, like iron, assists in electron transfer in the electron-transport chain. It is also an enzyme cofactor essential for iron absorption and transport. The other important function of copper is as an antioxidant. It is naturally present in several foods and is generally accessible as a dietary supplement.[1] A typical adult body has a total copper content of 50-120 mg.[2] The body maintains copper level balance through absorption from the intestine and the release of copper by the liver into bile. [3] Current studies indicate that copper deficiency may be more frequent than what was previously discovered, while copper toxicity is rare due to conventional diets. [4] Symptoms of mild to moderate copper deficiency are uncommon. More severe copper deficiency can cause anemia from the lack of iron mobilization in the body for red blood cell synthesis. Other signs and symptoms include growth retardation in children and neurological problems because copper is a cofactor for an enzyme that synthesizes myelin, which surrounds many nerves.

Dietary Reference Intakes for Copper

Table 10.5.2.1*: Dietary Reference Intakes for Copper*

DRI values (µg/day)		
Life stage group	RDA	UL
Infants (0-12 months)	–	ND[1]
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

[1] Not Determinable. Source: The National Academies Press (2006). Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. *The National Academies of Sciences Engineering Medicine.*

Dietary Sources of Copper

Copper is distributed in many foods and is abundant in organ meats, seafoods, nuts, and seeds. Wheat bran cereals, whole grains and cocoa products are also good sources of copper. The absorption of copper from foods may be reduced by excess intakes of zinc and the amino acid histidine in addition to high intakes of iron and fructose. Copper is also available as part of other ingredients in a multimineral supplement or by itself in a copper only supplement. Dietary supplements containing copper typically range from a few micrograms to 15 mg. [5]

Deficiency and Toxicity

Copper deficiency is rare but can occur due to genetic conditions, malabsorption, or excessive zinc intake. Clinical cases have documented symptoms such as anemia, neutropenia, and impaired immune function. One notable genetic disorder, **Menkes disease**, results from a mutation in the *ATP7A* gene, leading to poor copper absorption and transport. Affected infants typically present with hypotonia, seizures, kinky hair, and failure to thrive, often resulting in early mortality.

Copper toxicity — though uncommon — can occur through environmental exposure, over-supplementation, or in the inherited disorder **Wilson's disease**. This condition stems from a mutation in the *ATP7B* gene, impairing copper excretion into bile and leading to toxic accumulation in the liver, brain, and other tissues. Patients may present with hepatic dysfunction, psychiatric symptoms, or neurological signs such as tremors and dysarthria. A hallmark diagnostic feature is the presence of golden-brown or grayish-green rings in the cornea of the eyes, which are a result of copper deposits.

Understanding copper deficiency and toxicity is critically important, particularly for populations at risk or with genetic predispositions.

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10.6: Antioxidant Minerals — Se, Zn, Mn, S, Mo

In the body's constant battle against oxidative stress, the trace minerals, selenium (Se), zinc (Zn), manganese (Mn), sulfur (S), and molybdenum (Mo) are presented as "antioxidant minerals" in this textbook because they are essential for the proper functioning of antioxidant enzymes or systems that protect the body from oxidative stress caused by free radicals (reactive oxygen species, or ROS).

Although each of these minerals also serves other critically important biological functions, they collectively influence key antioxidant enzymes such as glutathione peroxidase, superoxide dismutase, and sulfite oxidase. This section explores how these essential micronutrients work synergistically within the body's complex antioxidant defense network, highlighting their dietary sources, biochemical functions, and the health consequences of their deficiency or excess.

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10.6.1: Selenium

Selenium (Se) — An introduction

Selenium is a cofactor of enzymes that release active thyroid hormone in cells and therefore low levels can cause similar signs and symptoms as iodine deficiency. The other important function of selenium is as an antioxidant. Selenium is a trace mineral that is part of the structure of at least 25 proteins in the body, with functions in reproduction, thyroid hormone metabolism, DNA synthesis, and antioxidant and immune protection.[6] As part of antioxidant enzymes, selenium helps to regenerate other antioxidants, including vitamin C. These enzymes also protect lipids from free radicals, and, in doing so, spare vitamin E. This illustrates how antioxidants work together to protect the body against free radical-induced damage.

Selenium Functions and Health Benefits

Around twenty-five known proteins require selenium to function. Some are enzymes involved in detoxifying free radicals and include glutathione peroxidases and thioredoxin reductase. As an integral functioning part of these enzymes, selenium aids in the regeneration of glutathione and oxidized vitamin C. Selenium as part of glutathione peroxidase also protects lipids from free radicals, and, in doing so, spares vitamin E. This is just one example of how antioxidants work together to protect the body against free-radical induced damage. Other functions of selenium-containing proteins include protecting endothelial cells that line tissues, converting the inactive thyroid hormone to the active form in cells, and mediating inflammatory and immune system responses.

Observational studies have demonstrated that selenium deficiency is linked to an increased risk of cancer. A review of forty-nine observational studies published in the May 2011 issue of the Cochrane Database of Systematic Reviews concluded that higher selenium exposure reduces overall cancer incidence by about 34 percent in men and 10 percent in women, but notes these studies had several limitations, including data quality, bias, and large differences among different studies.[1] Additionally, this review states that there is no convincing evidence from six clinical trials that selenium supplements reduce cancer risk.

Because of its role as a lipid protector, selenium has been suspected to prevent cardiovascular disease. In some observational studies, low levels of selenium are associated with a decreased risk of cardiovascular disease. However, other studies have not always confirmed this association and clinical trials are lacking.

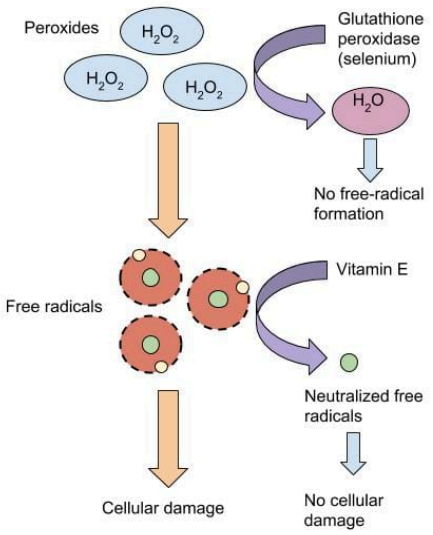


Figure 10.6.1.1: Selenium's Role in Detoxifying Free Radicals. Image by Allison Calabrese / CC BY 4.0

Food Sources of Selenium

Organ meats, muscle meats, and seafood have the highest selenium content. Grains and some nuts contain selenium when grown in selenium-containing soils. The selenium content of the soils used to grow animal feed can also affect the selenium content of animal products.

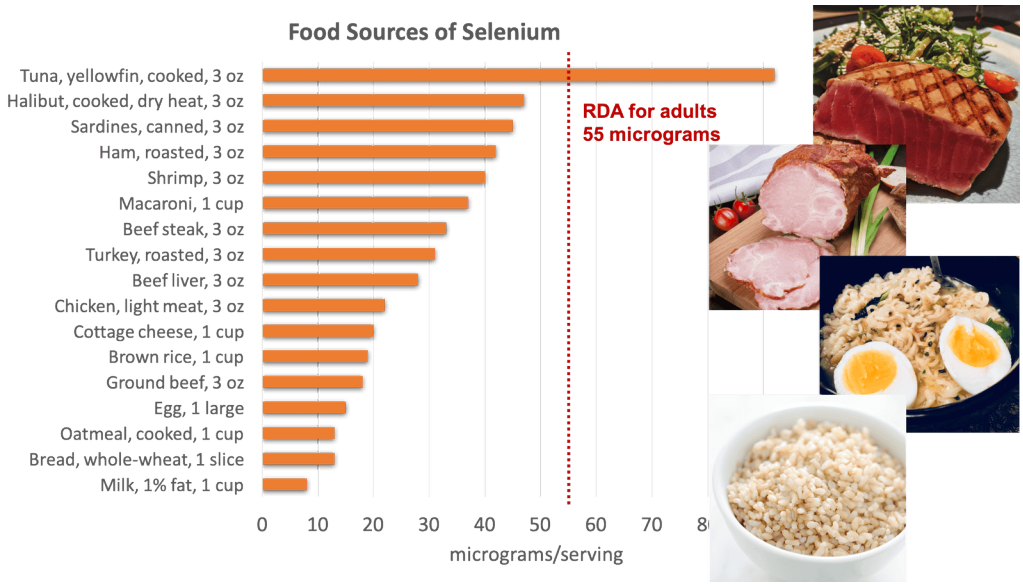


Figure 8.18. Dietary sources of selenium. Source: NIH *Office of Dietary Supplements*

Dietary Sources of Selenium

Table 10.6.1.2*: Selenium Contents of Various Foods*

Food	Serving	Selenium (mcg)	Percent Daily Value
Brazil nuts	1 oz.	544	777
Shrimp	3 oz.	34	49
Crab meat	3 oz.	41	59
Ricotta cheese	1 c.	41	59
Salmon	3 oz.	40	57
Pork	3 oz.	35	50
Ground beef	3 oz.	18	26
Round steak	3 oz.	28.5	41
Beef liver	3 oz.	28	40
Chicken	3 oz.	13	19
Whole-wheat bread	2 slices	23	33
Couscous	1 c.	43	61
Barley, cooked	1 c.	13.5	19
Milk, low-fat	1 c.	8	11
Walnuts, black	1 oz.	5	7

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

Selenium Deficiency and Toxicity

Selenium deficiency is very rare in the United States and other high-income countries where people consume foods sourced from variety of locations, where there are varying concentrations of selenium in the soil. Worldwide, people with a primarily vegetarian diet living in areas with low soil selenium levels and who only consume only locally grown or produced foods, including parts of China and Europe, may be at risk for selenium deficiency.[6]

As an example, Keshan Disease is a potentially fatal cardiomyopathy primarily associated with selenium deficiency. First identified in regions of China — Keshan County — with selenium-poor soil and near exclusive consumption of locally grown foods, the disease predominantly affects children and women of childbearing age. It is characterized by symptoms such as heart enlargement, arrhythmias, and congestive heart failure. Although selenium deficiency is the primary factor, the presence of a co-infecting Coxsackievirus also contributes to its pathogenesis. Supplementation with selenium has been shown to significantly reduce the incidence of Keshan Disease, highlighting the critical role of this trace element in cardiovascular health.

Chronic exposure to foods grown in soils containing high levels of selenium (above the UL of 400 micrograms per day) can cause brittle hair and nails, gastrointestinal discomfort, skin rashes, halitosis, fatigue, and irritability. Brazil nuts contain very high levels of selenium, so if eaten regularly could cause selenium toxicity. Selenium at doses several thousand times the RDA can cause acute toxicity, and when ingested in gram quantities, can be fatal.

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Dietary Reference Intakes for Selenium

The IOM has set the RDAs for selenium based on the amount required to maximize the activity of glutathione peroxidases found in blood plasma. The RDAs for different age groups are listed in Table 10.6.1.1.

Table 10.6.1.1: Dietary Reference Intakes for Selenium

Age Group	RDA Males and Females mcg/day	UL
Infants (0–6 months)	15*	45
Infants (7–12 months)	20*	65
Children (1–3 years)	20	90
Children (4–8 years)	30	150
Children (9–13 years)	40	280
Adolescents (14–18 years)	55	400
Adults (> 19 years)	55	400
*denotes Adequate Intake		

Query 10.6.1.1

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10.6.2: Zinc

Zinc — An Introduction

Zinc is critically important trace element that plays a central role in human growth and development, particularly during childhood. Inadequate zinc intake is widely recognized as a major contributor to stunted growth in children globally, especially in low-income populations where diets are predominantly plant-based and low in animal-source foods — the richest dietary sources of bioavailable zinc.

Beyond its critical role in child growth, zinc is also essential for immune function, wound healing, DNA synthesis, and cell division. It supports the activity of over 300 enzymes and more than 1,000 transcription factors, underscoring its extensive influence across physiological systems.[1]

Despite its importance, accurately assessing zinc status remains a major challenge in clinical and public health settings. Currently, there is no single reliable biomarker to determine individual zinc status. Although serum or plasma zinc concentrations are commonly used to estimate zinc deficiency at the population level, they are influenced by factors such as infection, inflammation, menstrual cycle and recent dietary intake, limiting their utility for individual diagnosis.

Zinc (Zn)

Zinc is a cofactor for over three hundred enzymes in the human body and plays a direct role in RNA, DNA, and protein synthesis. Zinc also is a cofactor for enzymes involved in energy metabolism. As the result of its prominent roles in anabolic and energy metabolism, a zinc deficiency in infants and children blunts growth. The reliance of growth on adequate dietary zinc was discovered in the early **1960s** in the Middle East where adolescent nutritional dwarfism was linked to diets containing high amounts of phytate. Cereal grains and some vegetables contain chemicals, one being phytate, which blocks the absorption of zinc and other minerals in the gut. It is estimated that half of the world's population has a zinc-deficient diet.[1]

This is largely a consequence of the lack of red meat and seafood in the diet and reliance on cereal grains as the main dietary staple. In adults, severe zinc deficiency can cause hair loss, diarrhea, skin sores, loss of appetite, and weight loss. Zinc is a required cofactor for an enzyme that synthesizes the heme portion of hemoglobin and severely deficient zinc diets can result in anemia.

As an antioxidant

- Key Role: Structural component of the antioxidant enzyme Cu/Zn superoxide dismutase (SOD).
- Function: Converts superoxide radicals ($O_2^{\diamond}$) into hydrogen peroxide (H_2O_2), which is then further detoxified.
- Other Actions: Zinc stabilizes membranes and prevents metal-induced oxidative damage by competing with redox-active metals like iron and copper.

Dietary Reference Intakes for Zinc

Table 10.6.2.1*: DDietary Reference Intakes for Zinc*

Age Group	RDA(mg/day)	UL(mg/day)
Infant (0–6 months)	2*	4
Infants (6–12 months)	3	5

Age Group	RDA(mg/day)	UL(mg/day)
Children (1–3 years)	3	7
Children (4–8 years)	5	12
Children (9–13 years)	8	23
Adolescents (14–18 years)	11 (males), 9 (females)	34
Adults (19 + years)	11 (males), 8 (females)	40
* denotes Adequate Intake		

Fact Sheet for Health Professionals: Zinc. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/. Updated February 11, 2016. Accessed November 10, 2017.

Dietary Sources of Zinc

Table 10.6.2.1: *Zinc Content of Various Foods*

Food	Serving	Zinc (mg)	Percent Daily Value
Oysters	3 oz.	74	493
Beef, chuck roast	3 oz.	7	47
Crab	3 oz.	6.5	43
Lobster	3 oz.	3.4	23
Pork loin	3 oz.	2.9	19
Baked beans	½ c.	2.9	19
Yogurt, low fat	8 oz.	1.7	11
Oatmeal, instant	1 packet	1.1	7
Almonds	1 oz.	0.9	6

Fact Sheet for Health Professionals: Zinc. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Zinc-HealthProfessional/. Updated February 11, 2016. Accessed November 10, 2017.

Query 10.6.2.1

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10.6.3: Manganese

Manganese — An introduction & overview

Manganese is a cofactor for enzymes that are required for carbohydrate and cholesterol metabolism, bone formation, and the synthesis of urea. Those who suffer from liver failure are at greater risk for manganese toxicity because the mineral's homeostasis is maintained largely by the liver with excretion of excess manganese occurring via bile. Manganese deficiency is uncommon. If a deficiency occurs from elimination from the diet, signs and symptoms include but are not limited to nausea, vomiting, dermatitis, decreased growth of hair and nails, and poor bone formation and skeletal defects.[1]

As an antioxidant

- Key Role: Cofactor for Mn-superoxide dismutase (Mn-SOD) — the mitochondrial form.
- Function: Detoxifies superoxide radicals produced during mitochondrial respiration.
- Significance: Critical for protecting mitochondria — the primary site of ROS generation — from oxidative stress.

Dietary Reference Intake of Manganese

The recommended intake for manganese is 2.3 mg per day for adult males and 1.8 mg per day for adult females. The Tolerable Upper Intake Level for adults is 11 mg/day.

Table 10.6.3.1*: Dietary Reference Intakes for Manganese*

Age group	AI (mg/day)	UL (mg/day)
Infants (0-6 months)	0.003	–
Infants (6-12 months)	0.6	–
Children (1-3 years)	1.2	2
Children (4-8 years)	1.5	3
Children (9-13 years)	1.9	6
Adolescents (14-18 years)	2.2 (males), 1.6 (females)	9
Adults (>18 years)	2.3 (males), 1.8 (females)	11

Source: The National Academies Press (2006). Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. The National Academies of Sciences Engineering Medicine. 350. Dietary Sources of Manganese: The best food sources for manganese are whole grains, nuts, legumes, and green vegetables.

Query 10.6.3.1

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10.6.4: Sulfur

Sulfur — An introduction

Sulfur is incorporated into protein structures in the body. Amino acids, methionine and cysteine contain sulfur which are essential for the antioxidant enzyme glutathione peroxidase. Some vitamins like thiamin and biotin also contain sulfur which are important in regulating acidity in the body. Sulfur is a major mineral with no recommended intake or deficiencies when protein needs are met. Sulfur is mostly consumed as a part of dietary proteins and sulfur containing vitamins.

Sulfur's Functional Role

Sulfur is the third most abundant mineral in our body after calcium and phosphorus.[1] Sulfur is incorporated into protein structures in the body such as keratin in hair and provides stabilization to these protein structures. One of it's key roles is the synthesis of 3'-phosphoadenosine-5'phosphosulfate (PAPS)[2] which is used in the biosynthesis of compounds essential in chondroitin in bones and cartilage, heparin and insulin.[3] Additionally, sulfur is an important component of the antioxidant enzyme glutathione peroxidase. Excess cysteine and methionine are oxidized to sulfate and excreted in the urine or stored as glutathione.[4]

As an antioxidant

- Key Role: Found in sulfur-containing amino acids like cysteine and methionine, which are precursors to
  - Glutathione (GSH) – a major intracellular antioxidant.
- Function: Glutathione directly neutralizes ROS and is a cofactor for glutathione peroxidase (a selenium-dependent enzyme).
- Additional Role: Involved in detoxification reactions through sulfur-containing compounds.

Dietary Reference Intakes for Sulfur

Sulfur is a major mineral with no recommended intake. Deficiencies are not found in those that meet protein requirements or in those with adequate consumption of sulfur-containing amino acids. Adverse effects were reported in individuals that ingest water sources with high levels of inorganic sulfur. Osmotic diarrhea may result and is of particular concern in infants. Animal studies showed that growth is stunted with inadequate sulfur intake from foods and beverages. Current data is insufficient to establish a Tolerable Upper Intake Level (UL).[5]

Dietary Sources of Sulfur

Dietary sources mainly come from sulfur-containing amino acids methionine and cysteine. Some vitamins like thiamin and biotin contain sulfur which are important in regulating acidity in the body. Sulfur can also be obtained from sulfur-containing foods such as garlic, onion and cruciferous vegetables.[6] Tap water also supplies sulfur but its concentration varies depending on location.[7] Dietary supplements such as chondroitin sulfate or glucosamine sulfate commonly used to aid bone and joint health also contain sulfur.[8]

Table 10.6.4.1: Sulfur Content in Various Foods

Food	Serving	Methionine (mg)	Cystine (mg)
Turkey breast	1 breast	7102	2442
Brazil nuts	1 cup	1495	407
Canned tuna	1 cup	1259	456

Food	Serving	Methionine (mg)	Cystine (mg)
Swiss Cheese, diced	1 cup	1035	383
Canned green peas	1 can	257	0.172
Egg, whole	1 large	189	136
Dried peaches	1 cup	139	46
Sweet potatoes	1 cup	134	43
Russet potatoes, baked	1 large potato (3” to 4-¼” diameter)	123	93
Whole-grain bread	1 slice	36	46
Broccoli	½ cup	34	24
Cauliflower	½ cup	16	13

Source: USDA Standard Reference Legacy Nutrient Search

Query 10.6.4.1

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10.6.5: Molybdenum

Molybdenum — An introduction & overview

Molybdenum also acts as a cofactor that is required for the metabolism of sulfur-containing amino acids, nitrogen-containing compounds found in DNA and RNA, and various other functions. Deficiency of molybdenum is not seen in healthy people, however, a rare metabolic effect called molybdenum cofactor deficiency is the result of an insufficient amount of molybdoenzymes in the body. Due to rapid excretion rates in the urine of the mineral, molybdenum toxicity is low in humans.

As an antioxidant

- Key Role: Cofactor for molybdoenzymes like sulfite oxidase, xanthine oxidase, and aldehyde oxidase.
- Function: These enzymes participate in redox reactions that can produce or eliminate reactive species.

Dietary Reference Intakes of Molybdenum

The recommended intake for molybdenum is 45 mcg per day for both adult males and females.

Table 10.6.5.1*: Dietary Reference Intakes for Molybdenum*

Age group	RDA (µg/day)	UL (µg/day)
Infants (0-6 months)		-
Infants (6-12 months)		-
Children (1-3 years)	17	300
Children (4-8 years)	22	600
Children (9-13 years)	34	1,100
Adolescents (14-18 years)	43	1,700
Adults (19-50 years)	45	2,000
Adults (51-70 years)	45	2,000
Adults (>71 years)	45	2,000

Source: The National Academies Press (2006). Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. The National Academies of Sciences Engineering Medicine. 356. Dietary Sources of Molybdenum: The food sources of molybdenum varies depending on the content in the soil in the specific region. Legumes, grain products, and nuts are rich sources of dietary molybdenum. Animal products, fruits, and most vegetables are low in molybdenum.[1]

Query 10.6.5.1

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10.7: Minerals and Energy Metabolism — I and Cr

In the complex network of energy metabolism, numerous vitamins and minerals play essential, interconnected roles. Although macronutrient-derived energy relies heavily on coenzymes formed from B vitamins and essential minerals like magnesium and iron — covered in previous sections — the two trace minerals, iodine (I) and chromium (Cr) also contribute uniquely to this process:

- Iodine is critical for the synthesis of thyroid hormones, which regulate basal metabolic rate and influence how the body utilizes energy.
- Chromium, though required in much smaller amounts, is thought to enhance insulin action and support glucose uptake into cells, playing a role in carbohydrate and lipid metabolism.

This section explores how these trace minerals contribute to the regulation and efficiency of energy metabolism, complementing the broader nutritional framework established by more prominent micronutrients.

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10.7.1: Iodine

Iodine (I)

Iodine is an essential trace mineral that the body needs to make thyroid hormones, which help regulate metabolism, support normal growth, and are critical for brain development.

Thyroid Hormone

The thyroid accumulates most absorbed iodine, keeping it for use to synthesize thyroid hormone. The following video shows the thyroid and describes its function.

YouTube Video

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View this YouTube Video online

Video 10.7.1.1: In this animation thyroid gland, its structure and function along with the hormones produced are described. https://www.youtube.com/watch?v=xKQa-MbZUPY

As mentioned in the video, the two primary forms of thyroid hormone are triiodothyronine (T3) and thyroxine (T4).

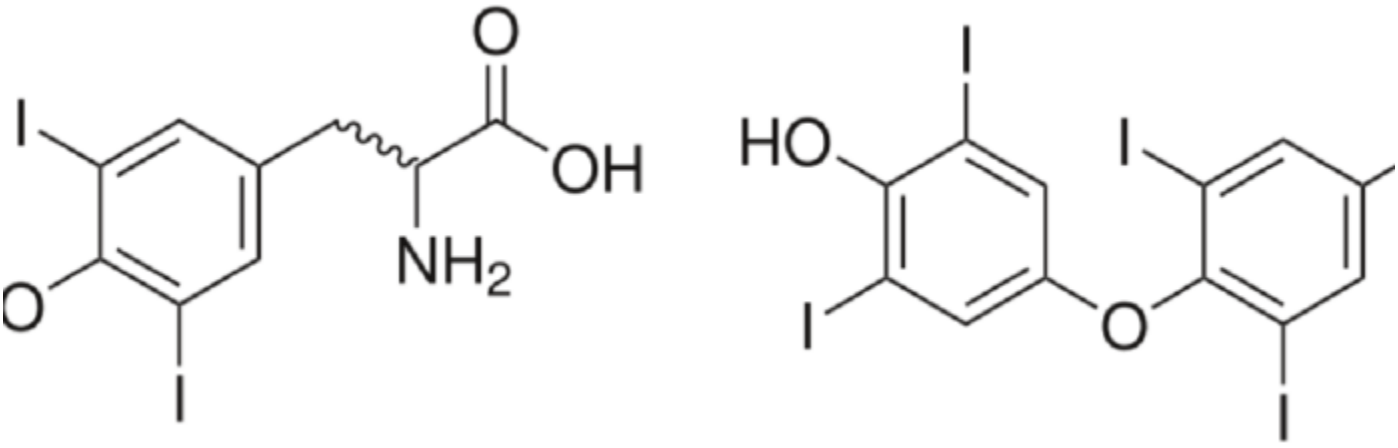


Figure 10.7.1.4: (left) The structure of triiodothyronine (T3)11 and (right) The structure of thyroxine (T4)12

T4 is the primary circulating form, and is really a prohormone that is converted to the active T3 form.

Query 10.7.1.4

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Goiter

When the diet lacks enough iodine, the thyroid gland can't produce enough thyroid hormone, leading to a condition called hypothyroidism. Common symptoms include tiredness, feeling cold, weight gain, constipation, dry skin, and depression. A noticeable sign of long-term iodine deficiency is the development of a goiter — an enlarged thyroid gland in the neck. While goiter is the most visible symptom, the effects of iodine deficiency can be especially serious during infancy, childhood, and adolescence, when proper growth and development depend on adequate thyroid hormone levels.



Figure 10.7.1.1: Iodine Deficiency: Goiter. A large goiter by Dr. J.S.Bhandari, India / CC BY-SA 3.0

Congenital Iodine Deficiency Syndrome (CIDS)

Thyroid hormone plays a major role in brain development and growth, and fetuses and infants born to mothers with severe iodine deficiency develop a condition known as Congenital Iodine Deficiency Syndrome (CIDS), also called cretinism, in which physical and neurological impairment can be severe.



Figure 10.7.1.1: Iodine Deficiency: Congenital Iodine Deficiency Syndrome (CIDS), also called cretinism William Seaman Bainbridge, Public domain, via Wikimedia Commons / CC BY-SA 3.0

The World Health Organization (WHO) estimates iodine deficiency affects over two billion people worldwide. The WHO calls iodine deficiency "the world's most prevalent, yet easily preventable, cause of brain damage18."

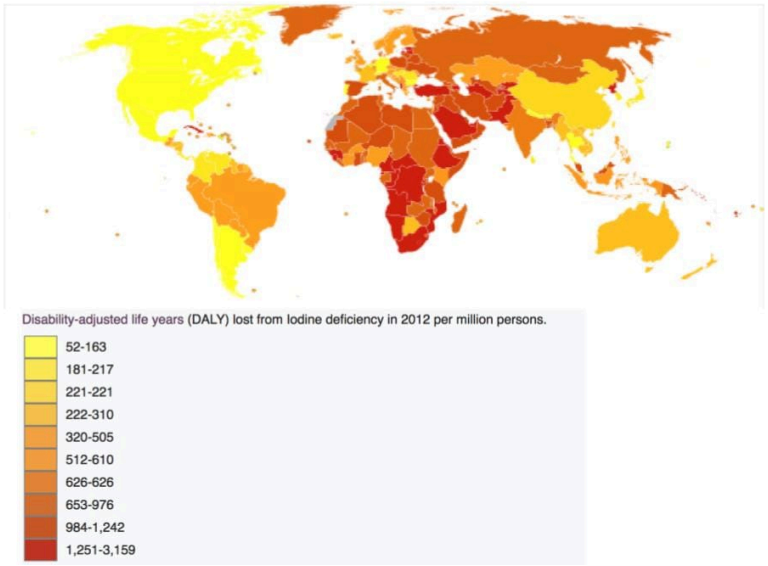


Figure 10.7.1.2: Deaths Due to Iodine Deficiency Worldwide in 2012. Image by Chris55 / CC BY 4.0

Preventing Iodine Deficiency

By saying it is easily preventable, WHO is referring to the ability of salt iodization to prevent brain development problems. The following New York Times article talks about how salt iodization may be the cheapest way to raise the world's IQ.

Web Link

In Raising the World's I.Q., the Secret's in the Salt

How the Iodine Global Network supports salt iodization

The Iodine Global Network supports salt iodization efforts worldwide. The Iodine Global Network is a non-profit whose mission is the sustainable elimination of iodine deficiency worldwide. Its basic strategy is to ensure that *salt is iodized forever*, because salt iodization is the cheapest, most scalable way to ensure adequate iodine intake for populations.

Specifically, IGN does:

- Advocacy / policy support: working with governments and salt industry stakeholders to adopt or maintain universal salt iodization (USI) legislation or regulation.
- Technical assistance: helping countries with guidance on how to iodize salt properly, monitor iodine levels in salt, manage supply of the iodine additive (like potassium iodate or iodide), ensuring quality control, etc.
- Monitoring, data, and research: tracking how many households consume iodized salt, how much iodine people are getting, where progress is or isn't happening; also publishing guidance for new challenges (e.g. dealing with processed foods that use salt) and adapting programs.
- Partnerships: working with WHO, UNICEF, national governments, salt producers, NGOs, funders, etc., to mobilize resources and coordinate action globally and in countries with high need.

Examples of IGN's salt iodization efforts

- In countries like Sudan, IGN's advocacy combined with technical support helped enact legislation for mandatory salt iodization and improve the salt producers' capacity.
- IGN has helped pilot programs to include salt used in processed foods (condiments, industrial processed foods) in iodine strategies, to reach populations that don't always get adequately iodized household salt.
- In Sri Lanka, IGN has worked with the government to widen iodized salt coverage.

Disruptions to successful salt iodization programs

How Fukushima disrupted salt iodization: the case of Cambodia

The Fukushima Daiichi nuclear disaster in March 2011 had a series of unintended ripple effects on global iodine supply chains, which in turn affected salt iodization programs in several low- and middle-income countries. Cambodia provides an illustrative example of how these global disruptions played out at the national level.

Iodine supply and price shocks: Following Fukushima, global demand for stable iodine compounds (such as potassium iodide) surged due to their use in radiation protection, while some iodine extraction and refining operations in Japan were also disrupted. This combination led to sharp increases in the global prices of iodine and iodate — reportedly tripling in 2011.

Rising costs for iodization: As the price of potassium iodate rose, salt producers around the world faced increased production costs. In Cambodia, where many producers are small- or medium-scale enterprises, the higher cost of iodine additive created challenges for maintaining routine iodization and equipment upkeep.

Program challenges and monitoring pressures: The higher input costs, along with reduced availability of iodate, made it more difficult for some producers to consistently meet iodization standards. At the same time, regulatory and monitoring systems faced strain, as governments and partners worked to adapt to the new market conditions.

Temporary setbacks after progress: Prior to Fukushima, Cambodia's salt iodization program had been highly successful — significantly reducing iodine deficiency and related disorders such as goiter among schoolchildren by around 2010. The price and supply shocks that followed 2011 led to temporary setbacks, highlighting the vulnerability of national nutrition programs to global supply disruptions.

Diversion of iodine supplies: Because of the urgent need for iodine compounds in radiation response measures after

Fukushima, part of the global supply was redirected for medical and emergency use, further tightening availability for nutrition programs. This reallocation underscored how competing global demands for a single micronutrient can have far-reaching effects on public health interventions in unrelated sectors.

Iodine Toxicity

Iodine toxicity is rare, but like iodine deficiency, it can result in thyroid enlargement, and hypothyroidism or hyperthyroidism. Acute toxicity results in gastrointestinal irritation, abdominal pain, nausea, vomiting, and diarrhea2.

Dietary Reference Intakes for Iodine

Table 10.7.1.1*: Dietary Reference Intakes for Iodine*

Age Group	RDA Males and Females mcg/day	UL
Infants (0–6 months)	110*	
Infants (7–12 months)	130*	
Children (1–3 years)	90	200
Children (4–8 years)	120	300
Children (9–13 years)	150	600
Adolescents (14–18 years)	150	900
Adults (> 19 years)	150	1,100
*denotes Adequate Intake		

Health Professional Fact Sheet: Iodine. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/factsheets/Iodine-HealthProfessional/. Updated June 24, 2011. Accessed November 10, 2017.

Dietary Sources of Iodine

The mineral content of foods is greatly affected by the soil from which it grew, and thus geographic location is the primary determinant of the mineral content of foods. For instance, iodine comes mostly from seawater so the greater the distance from the sea the lesser the iodine content in the soil.

Table 10.7.1.2*: Iodine Content of Various Foods*

Food	Serving	Iodine (mcg)	Percent Daily Value
Seaweed	1 g.	16 to 2,984	11 to 1,989
Cod fish	3 oz.	99	66
Yogurt, low fat	8 oz.	75	50
Iodized salt	1.5 g.	71	47
Milk, reduced fat	8 oz.	56	37
Ice cream, chocolate	½ c.	30	20
Egg	1 large	24	16
Tuna, canned	3 oz.	17	11
Prunes, dried	5 prunes	13	9
Banana	1 medium	3	2

Health Professional Fact Sheet: Iodine. National Institute of Health, Office of Dietary Supplements. https://ods.od.nih.gov/

factsheets/Iodine-HealthProfessional/. Updated June 24, 2011. Accessed November 10, 2017.

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10.7.2: Chromium

Chromium (Cr)

The functioning of chromium in the body is less understood than that of most other minerals. It enhances the actions of insulin so it plays a role in carbohydrate, fat, and protein metabolism.

Potential Benefits

Over the past decade, research on chromium supplementation and its potential role in preventing or managing type 2 diabetes has expanded considerably. Although early findings were largely inconclusive, more recent studies — including several large randomized controlled trials and meta-analyses — have provided a clearer, though still nuanced, picture. Chromium, particularly in its trivalent forms such as chromium picolinate, chromium yeast, and chromium chloride, appears to modestly improve measures of glycemic control in individuals with type 2 diabetes (Asbaghi et al., 2020). Supplementation in doses typically ranging from 200 to 400 micrograms per day over several months has been associated with small but statistically significant reductions in fasting plasma glucose, hemoglobin A_1c (HbA_1c), fasting insulin, and indices of insulin resistance such as HOMA-IR. These effects tend to be more pronounced in individuals with poorer baseline glycemic control and when interventions are of longer duration.

The benefits of chromium supplementation may extend modestly beyond glucose regulation. Some studies have reported improvements in lipid profiles — such as reductions in triglycerides and total cholesterol, and occasional increases in HDL cholesterol — as well as reductions in markers of oxidative stress and diastolic blood pressure. However, findings across studies are inconsistent, and the overall magnitude of these effects is small. Evidence for chromium's role in promoting weight loss or altering body composition remains weak; most trials have shown little to no effect on body weight, body mass index, or waist circumference, although slight improvements in fat mass have been noted among older adults in some studies.

Despite growing evidence of modest benefits, significant limitations remain. Study results are highly heterogeneous due to differences in chromium form, dosage, study duration, and participant characteristics. Many trials are short-term and small in scale, and long-term safety data — especially for high-dose supplementation — are limited. Trivalent chromium appears well tolerated at typical supplemental levels, but the safety of prolonged or high-dose use is not yet fully understood.

Taken together, recent evidence suggests that chromium supplementation could play a limited, adjunctive role in managing type 2 diabetes rather than serving as a primary treatment. Modest improvements in glycemic control are most likely when appropriate forms and doses are used consistently over several months. However, chromium should not replace established therapies such as dietary modification, physical activity, and pharmacologic management. Further high-quality, long-duration trials are needed to determine optimal dosage, clarify mechanisms, confirm safety, and identify which individuals are most likely to benefit from supplementation.

Deficiency

If a deficiency of chromium occurs in the body, signs and symptoms include weight loss, peripheral neuropathy, elevated plasma glucose concentrations or impaired glucose use, and high plasma free fatty acid concentrations.

Toxicity

Although toxicity of the mineral is a low risk in humans, it can cause DNA damage, organ damage, and renal problems. Tissues that are high in chromium include the liver, spleen, and bone.[1]

Dietary Reference Intakes for Chromium

The recommended intake for chromium is 35 mcg per day for adult males and 25 mcg per day for adult females. There is insufficient evidence to establish an UL for chromium.

Table 10.7.2.1: *Dietary Reference Intakes for Chromium*

Age Group	AI (µg/day)
Infants (0-6 months)	0.2
Infants (6-12 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)

Source: The National Academies Press (2006). Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. *The National Academies of Sciences Engineering Medicine*. 296. Dietary Sources For Chromium: Dietary sources of chromium include meats, nuts, and whole grains. [2]

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Refernces

1. Gropper, S. A. S., Smith, J. L., & Carr, T. P. (2018). Advanced nutrition and human metabolism. Boston, MA: Cengage Learning. ↵
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CHAPTER 11: NUTRITION AND PHYSICAL ACTIVITY

Learning Objectives

After completing this unit, you should be able to:

1. Identify the four essential elements of physical fitness and describe each element.
2. Describe the key guidelines for physical activity for adults.
3. Identify the specific physical, mental, and emotional benefits of physical activity.
4. Explain the FITT principle and what the acronym stands for.
5. Identify the energy systems that provide the body with fuel for physical activity.
6. Describe how duration and intensity impact the types of fuel used for physical activity.
7. Understand how nutrient needs differ for athletes, including energy needs, macronutrient needs and micronutrient needs
8. Describe how hydration status impacts exercise performance
9. Identify the purpose of sports drinks and their role in combating hyponatremia

11.1: Introduction to Nutrition and Physical Activity

11.2: Essential Elements and Benefits of Physical Fitness

11.3: Fuel Sources for Exercise

11.4: Nutrient Needs for Athletes

11.5: Nutrition-Relevant Concerns in Sports Performance

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11.1: Introduction to Nutrition and Physical Activity

In this course, our focus is on how nutrients support health. However, enjoying good health is about so much more than simply meeting nutrient needs. As we discussed in Unit 1, 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.” For most people, being physically active contributes to all three of those elements of health: physical, mental, and social well-being.



Figure 11.1.1: Women working out together photo by Luis Quintero on Unsplash (license information)

Not surprisingly, the more you ask of your body in terms of physical activity, the more attention you’ll need to give to fueling it with nutrients. With optimal nourishment, your body will in turn reward you with improved performance and energy levels. Fueling a physically active body is based on the same principles we’ve discussed throughout this course, but requirements for energy and some nutrients are increased. In this unit, we’ll cover the elements of physical fitness, the benefits of physical activity, and recommendations for fueling an active lifestyle and athletic performance.

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11.2: Essential Elements and Benefits of Physical Fitness

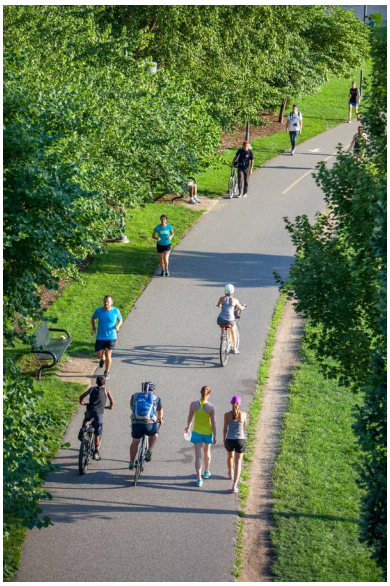
Becoming and staying physically fit is an important part of achieving optimal health. A well-rounded exercise program can improve your health in a number of ways. It keeps the heart and lungs strong, strengthens muscles and bones, helps to protect against chronic disease, improves brain and mental health, and can support healthy body weight. **There are four main components of physical fitness as it relates to health and function: cardiorespiratory fitness, musculoskeletal fitness, flexibility, and balance.** [1] Each component offers specific health benefits, but optimal health requires some degree of balance between all four. (**Speed**, or the ability to move the body quickly, is also considered a component of physical fitness, but it is less related to health and more relevant to competitive athletes.[1])

Some forms of exercise can help build multiple types of fitness. For example, riding a bicycle not only builds cardiorespiratory endurance; it can also improve muscle strength and endurance. Some forms of yoga and Pilates can also build muscle strength and endurance, along with flexibility and balance. However, building fitness in all four categories generally requires incorporating a range of activities into your regular routine. As you increase physical activity, you will notice that you are able to continue your activity longer and with greater ease.

The Essential Elements of Physical Fitness

Cardiorespiratory Fitness

Cardiorespiratory fitness is defined as "the ability to perform large-muscle, whole-body exercise at moderate-to-vigorous intensities for extended periods of time," according to the Physical Activity Guidelines for Americans.[1] **Cardiorespiratory fitness is built by aerobic activity, during which you move your body's large muscle groups in a continuous and rhythmic way, and your heart and breathing rate increase.** Examples of aerobic activities include walking, running, swimming, jumping rope, and riding a bike.

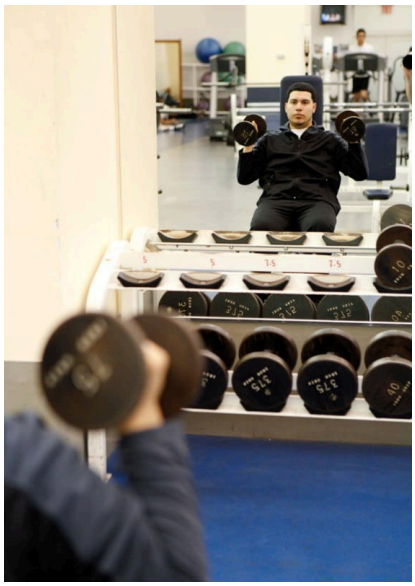


Aerobic physical activity can range in level of intensity; for example, brisk walking is considered moderate intensity, and running or jogging is considered vigorous intensity. As intensity increases, so do heart and breathing rates to meet increased demand for oxygen in working muscles. Regular, moderate aerobic activity—about thirty minutes at a time on five days per week—trains the body to deliver oxygen more efficiently, which strengthens the heart and lungs and reduces the risk of cardiovascular disease. Strengthening your heart muscle and increasing the blood volume pumped in each heartbeat boosts your ability to supply your body's cells with oxygen and nutrients and remove carbon dioxide and metabolic wastes. It also leads to a lower resting heart rate for healthy individuals. Aerobic physical activity can also help maintain a healthy weight.[1]

Many aerobic activities also count as **bone-strengthening activity**, which promotes bone growth and strength by producing a force on the body's bones. Weight-bearing activities like running, walking, and doing jumping jacks are considered bone-strengthening, whereas activities like swimming and biking that put less force on the body's bones are not. Bone-strengthening activities are especially important during childhood and adolescence, when they promote greater bone mass and strength and improved bone structure. In older adults, participating in aerobic and bone-strengthening activities slows the decline in bone density that often occurs with aging.

Musculoskeletal Fitness

Musculoskeletal fitness is defined as "the integrated function of **muscle strength, muscle endurance**, and **muscle power** to enable performance."[1] Musculoskeletal fitness is developed and maintained by weight or resistance training, often called **anaerobic exercise**. **Anaerobic exercise consists of short duration, high intensity movements that rely on immediately available energy sources and require little or no oxygen during the activity.** This type of training includes lifting weights, working with resistance bands, using body weight (such as for push-ups and pull-ups), and doing work such as carrying heavy loads or vigorous yard work. Building musculoskeletal fitness is not just for athletes and bodybuilders—it's important for children, older adults, and everyone in between. The support that your muscles provide allows you to work, play, and live more efficiently.



Muscle-strengthening activity often involves the use of resistance machines, resistance bands, free weights, or other tools. However, you do not need to pay for a gym membership or expensive equipment to strengthen your muscles. Homemade weights, such as plastic bottles filled with sand, can work just as well. You can also use your own body weight and do push-ups, leg squats, abdominal crunches, planks, and other exercises to build your muscles. What is important is that your training incorporates exercises that together will work all the major muscle groups of the body, including the legs, hips, chest, back, shoulders, arms, and abdomen. To improve muscle strength, do one to three sets of 8 to 12 repetitions per exercise, with enough weight that it is difficult to do another repetition at the end of a set.

If strength training is performed at least twice per week, it can help improve muscular fitness and bone health, as well as manage health conditions like diabetes, arthritis, hypertension, and many others. Strength training can also help to maintain muscle mass during weight loss.[1,2]

Flexibility

Flexibility is the range of motion available to your joints. Many types of physical activity, including dancing, yoga, and martial arts, require significant joint movement, and improving flexibility may allow you to do these activities more easily and fluidly. Even daily activities such as housework and getting in and out of the car are easier with more functional flexibility, especially as we age.

Yoga, tai chi, Pilates, and stretching exercises can increase flexibility. These exercises can improve your range of motion and promote better posture and balance. However, contrary to popular belief, research on stretching has shown that it does not reduce risk of injury or later muscle soreness.[3]



Balance

Balance is the ability to maintain equilibrium during movement or while stationary. Many forms of physical activity and daily living activities require balance. Exercises to improve balance are especially important in older adults, as balance tends to deteriorate with age, putting older adults at greater risk of falls and fractures.[4] Activities that can improve balance include walking backward, standing on one leg, and using a wobble board. Activities such as tai chi and yoga can also improve balance, and especially for older adults, can also count as moderate-intensity aerobic activity.[1]

Physical Activity Benefits and Guidelines

Regular physical activity is one of the best things you can do to achieve optimal health. Individuals who are physically active for 150 minutes per week lower the risk of dying early by 33 percent compared to those who are inactive.[3] The 2018 Physical Activity Guidelines for Americans were issued by the Department of Health and Human Services (HHS) to provide evidence-based guidelines to Americans aged three and older about how to improve health and reduce chronic disease risk through physical activity. The full guidelines are available online at the following link: Physical Activity Guidelines for Americans.[4]

Key Guidelines for Adults

- Adults should move more and sit less throughout the day. Some physical activity is better than none. Adults who sit less and do any amount of moderate-to-vigorous physical activity gain some health benefits.
- For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) 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, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Preferably, aerobic activity should be spread throughout the week.
- Additional health benefits are gained by engaging in physical activity beyond the equivalent of 300 minutes (5 hours) of moderate-intensity physical activity a week.
- Adults should also do muscle-strengthening activities of moderate or greater intensity and that involve all major muscle groups on 2 or more days a week, as these activities provide additional health benefits.

Source: 2018 Physical Activity Guidelines for Americans

Improving your overall fitness involves sticking with a physical activity program on a regular basis, so that being active becomes part of your routine. Choosing physical activity that you enjoy will increase the likelihood of sustaining the activity. If you are nervous or unsure about becoming more active, check with your doctor about the best way to get started. The good news is that moderate-intensity activities such as brisk walking are very safe for most people, and the health advantages of becoming active far outweigh the risks. Physical activity can also be social; regularly meeting a friend for a walk or joining a hiking group can make getting active more fun and social, plus help you stick to your plan. Physical activity provides a wealth of benefits—physical, mental, and emotional.



Table 10.1. Physical and emotional benefits of exercise.

Physical Benefits	Mental and Emotional Benefits
Longer life: A regular exercise program can reduce your risk of dying early from heart disease, certain cancers, and other leading causes of death.	**Mood improvement:** Aerobic activity, strength-training, and more contemplative activities such as yoga, all help break cycles of worry and distraction, effectively draining tension from the body.
Healthier weight: Exercise, along with a healthy, balanced eating plan, may help you lose extra weight, maintain weight loss, or prevent excessive weight gain.	**Depression relief:** Exercise can produce antidepressant effects in the body. Studies have shown that physical activity reduces the risk of and helps people cope with the symptoms of depression.
Cardiovascular disease prevention: Being active boosts HDL cholesterol and decreases unhealthy triglycerides, which reduces the risk of cardiovascular diseases.	**Cognitive skills retention:** Regular physical activity can help people maintain thinking, learning, and judgment as they age.
Management of chronic conditions: A regular routine can help to prevent or manage a wide range of conditions and concerns, such as metabolic syndrome, type 2 diabetes, depression, arthritis, and certain types of cancer.	**Better sleep:** A good night's sleep is essential for clear thinking, and regular exercise promotes healthy, sound sleep. It can also help you fall asleep faster and deepen your rest, promoting better mental and emotional wellbeing.

Physical Benefits	Mental and Emotional Benefits
Energy boosts: Regular physical activity can improve muscle tone and strength and provide a boost to your cardiovascular system. When the heart and lungs work more efficiently, you have more energy.	
Strong bones: Research shows that aerobic activity and strength training can slow the loss of bone density that typically accompanies aging.	

The FITT Principle

One helpful tool for putting together an exercise plan is the **FITT**. FITT stands for:

- Frequency – how often you exercise
- **Intensity** – how hard you work during your exercise session
- **Time** – how long you exercise for
- **Type**– what kind of exercise you do

You can manipulate the principles of FITT to better meet your exercise goals and to boost your motivation to exercise. You will be more likely to stick to a workout plan that is fun, has flexibility, and works with your lifestyle. By changing up the types of exercise you do, varying the intensity of your workouts, and choosing days of the week and times of the day that work best with your schedule, you can create a plan for success with your exercise goals. As you design your physical activity plan, make sure you find ways to move that you truly enjoy and can sustain and consider the components of the FITT principle to establish more detailed goals and create purpose for your workouts.

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- [1]2018 Physical Activity Guidelines for Americans. US Department of Health and Human Services. Retrieved August 28, 2020, from https://health.gov/paguidelines/second-edition/.
- [2]American College of Sports Medicine. (2019). *Resistance Training for Health*. Accessed August 28, 2020, from https://www.acsm.org/docs/default-source/files-for-resource-library/resistance-training-for-

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11.3: Fuel Sources for Exercise

The human body uses carbohydrate, fat, and protein in food and from body stores for energy to fuel physical activity. These essential nutrients are needed regardless of the intensity of the activity you are doing. If you are lying down and reading a book or running a marathon, these macronutrients are always needed in the body. However, in order for these nutrients to be used as fuel for the body, their energy must be transferred into the high energy molecule known as adenosine triphosphate (ATP). ATP is the body's immediate fuel source and can be generated either with ***aerobic metabolism*** in the presence of oxygen or ***anaerobic metabolism*** without the presence of oxygen. The type of metabolism that is predominately used during physical activity is determined by the availability of oxygen and how much carbohydrate, fat, and protein are used.

Anaerobic and Aerobic Metabolism

Anaerobic metabolism occurs in the cytosol of the muscle cells. As seen in Figure 10.1., a small amount of ATP is produced in the cytosol without the presence of oxygen. **Anaerobic metabolism uses glucose as its only source of fuel** and produces pyruvate and lactic acid. Pyruvate can then be used as fuel for aerobic metabolism. **Aerobic metabolism takes place in mitochondria of the cell and is able to use carbohydrates, protein, or fat as fuel sources**. Aerobic metabolism is a much slower process than anaerobic metabolism, but it can produce much more ATP and is the process by which the majority of the ATP in the body is generated.

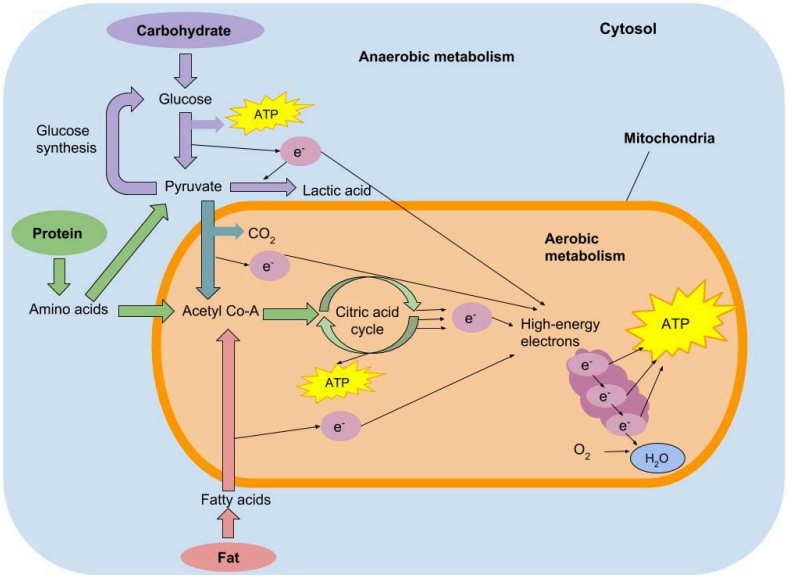


Figure 10.1. Anaerobic vs aerobic metabolism. Note that carbohydrate is the only fuel utilized in anaerobic metabolism, but all three macronutrients can be used for fuel during aerobic metabolism.

Physical Activity Duration and Fuel Use

The respiratory system plays a vital role in the uptake and delivery of oxygen to muscle cells throughout the body. Oxygen is inhaled by the lungs and transferred from the lungs to the blood, where the cardiovascular system circulates the oxygen-rich blood to the muscles. The oxygen is then taken up by the muscles and can be used to generate ATP. When the body is at rest, the heart and lungs are able to supply the muscles with adequate amounts of oxygen to meet the energy needs for aerobic metabolism. However, during physical activity, your muscles need more energy and oxygen. In order to provide more oxygen to the muscle cells, your heart rate and breathing rate will increase. The amount of oxygen that is delivered to the tissues via the cardiovascular and respiratory systems during exercise depend on the duration, intensity and physical conditioning of the individual.

- **During the first few steps of exercise**, your muscles are the first to respond to the change in activity level. Your lungs and heart do not react as quickly, and during those beginning steps, they can't yet increase the delivery of oxygen. In order for our bodies to get the energy that is needed in these beginning steps, the muscles rely on a small amount of ATP that is stored

in resting muscles. The stored ATP is able to provide energy for only a few seconds before it is depleted. Once the stored ATP is just about used up, the body resorts to another high-energy molecule known as ***creatine phosphate*** to convert ADP (adenosine diphosphate) to ATP. After about 10 seconds, the stored creatine phosphate in the muscle cells are also depleted as well.

- **About 15 seconds into exercise,** the stored ATP and creatine phosphate are used up in the muscles. The heart and lungs have still not adapted to the increased oxygen need, so the muscles must begin to produce ATP by anaerobic metabolism (without oxygen). Anaerobic metabolism can produce ATP at a rapid pace but only uses glucose as its fuel source. The glucose is obtained from muscle glycogen. At around 30 seconds, anaerobic pathways are operating at their full capacity, but because the availability of glucose is limited, it cannot continue for a long period of time.
- **As your exercise reaches two to three minutes**, your heart rate and breathing rate have increased to supply more oxygen to your muscles. Aerobic metabolism is the most efficient way of producing ATP; it produces significantly more ATP for each molecule of glucose than anaerobic metabolism. Although the primary source of ATP in aerobic metabolism is carbohydrates, fatty acids and protein can also be used as fuel to generate ATP.

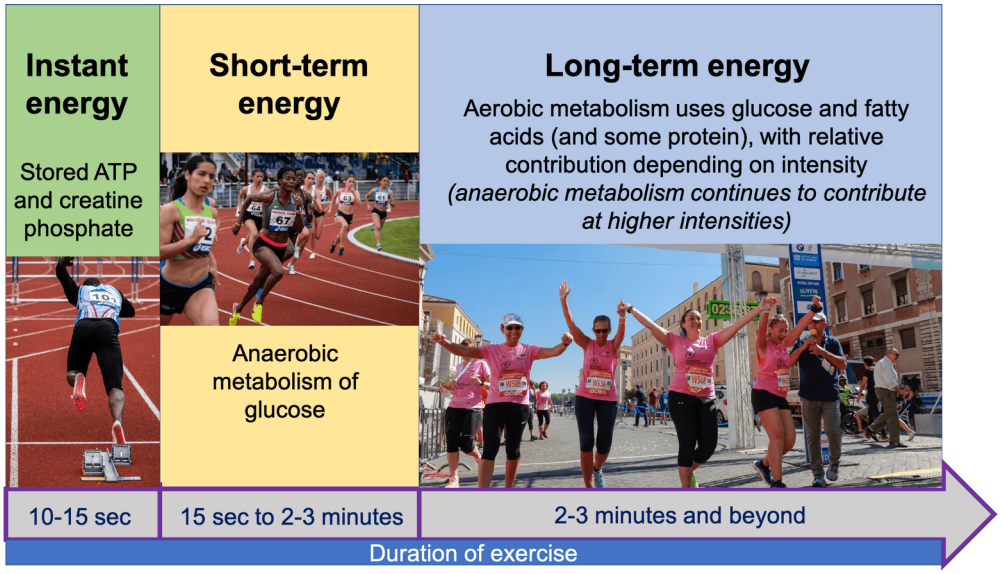


Figure 10.2. Energy systems used to fuel exercise change with duration of exercise. The ATP-creatine phosphate system is used up within seconds. The short-term and long-term systems kick in and provide energy for exercise as the duration of the workout goes on.

The fuel sources for anaerobic and aerobic metabolism will change depending on the amount of nutrients available and the type of metabolism.

- **Glucose** may come from blood glucose (which is from dietary carbohydrates, liver glycogen, and glucose synthesis) or muscle glycogen. Glucose is the primary energy source for both anaerobic and aerobic metabolism.
- **Fatty acids** are stored as triglycerides in muscles, but about 90 percent of stored energy is found in adipose tissue. As low- to moderate-intensity exercise continues using aerobic metabolism, fatty acids become the predominant fuel source for exercising muscles.
- Although **protein** is not considered a major energy source, small amounts of amino acids are used while resting or doing an activity. The amount of amino acids used for energy metabolism increases if the total energy intake from your diet does not meet your nutrient needs or if you are involved in long endurance exercise. When amino acids are broken down and the nitrogen-containing amine group is removed, the remaining carbon molecule can be broken down into ATP via aerobic metabolism, or it can be used to make glucose. When exercise continues for many hours, amino acid use will increase as an energy source and for glucose synthesis.

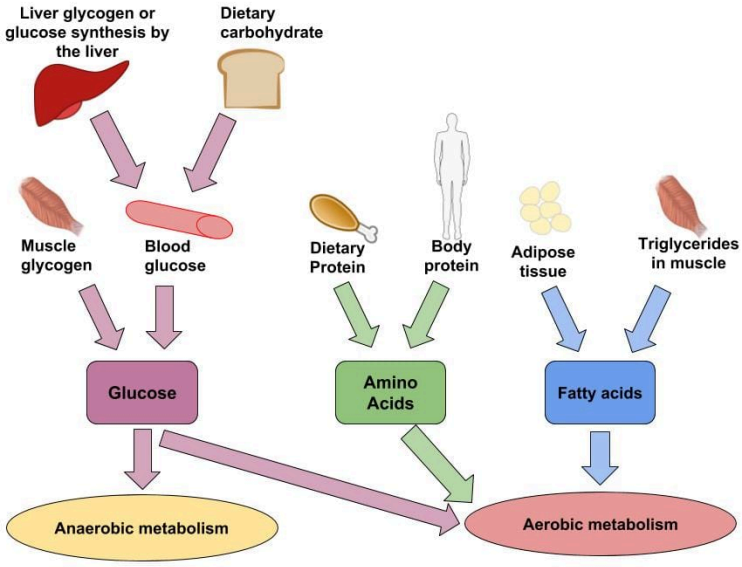


Figure 10.3. Fuel sources for anaerobic and aerobic metabolism. Both dietary sources and body storage of carbohydrates, fat, and protein can all be used to fuel activity. Amount varies depending on duration and intensity of the activity.

Physical Activity Intensity and Fuel Use

Exercise intensity determines the contribution of different fuel sources used for ATP production. Both anaerobic and aerobic metabolism combine during exercise to ensure that the muscles are equipped with enough ATP to carry out the demands placed on them. The contribution from each type of metabolism depends on the intensity of an activity. During low-intensity activities, aerobic metabolism is used to supply enough ATP to muscles. However, during high-intensity activities, more ATP is needed, so the muscles must rely on both anaerobic and aerobic metabolism to meet the body's demands.

Table 10.2. Summary of fuels used for activities of different intensities and durations.

Activity Intensity	Activity Duration	Preferred Fuel	Oxygen Needed?	Activity Example
Very high	30 sec – 3 min	Glucose	No – anaerobic	Sprinting
High	3 min – 20 min	Glucose	Yes – aerobic	Jogging
Low to moderate	>20 min	Fat	Yes – aerobic	Walking

During low-intensity activities, the body will use aerobic metabolism over anaerobic metabolism, because it is more efficient and produces larger amounts of ATP. **Fatty acids are the primary energy source during low-intensity activity.** With fat reserves in the body being almost unlimited, low-intensity activities are able to continue for a long time. Along with fatty acids, a small amount of glucose is used as well. Glucose differs from fatty acids, because glycogen storages can be depleted. As glycogen stores are depleted, the glucose supply becomes depleted, and fatigue will eventually set in.

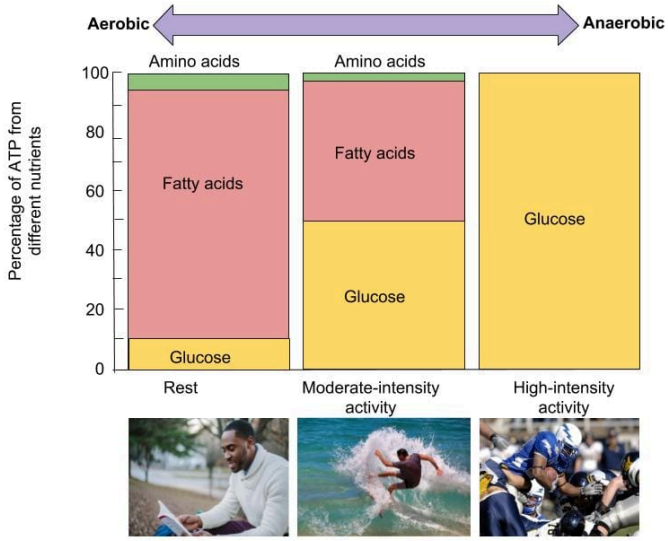


Figure 10.4. The effect of exercise intensity on fuel sources. Anaerobic exercise utilizes only glucose for fuel. As activities become more aerobic, the body can utilize fatty acids and, to a small extent, amino acids, for energy production.

One important clarification about exercise intensity and fuel sources is the concept of the fat-burning zone. Many people think that in order to lose body fat, they should exercise at a lower intensity so that fat is the primary fuel source. **The fat-burning zone is typically referred to as a low-intensity aerobic activity that keeps your heart rate between 60 and 69 percent of maximum heart rate. The cardio zone, on the other hand, is a high-intensity aerobic activity that keeps the heart rate between about 70 and 85 percent of maximum heart rate.** So which zone do you burn the most fat in? Technically, your body burns a higher percentage of calories from fat during a low-intensity aerobic activity. When you begin a low-intensity activity, about 50% of the calories burned come from fat, whereas in the cardio zone only 40% come from fat. However, this isn't the whole story. **High-intensity activity burns more total calories per minute. At this higher rate of energy expenditure, you can burn just as much or more total fat and more total calories as during a lower intensity activity.** If weight loss is one of your goals, high-intensity activities will burn more total calories, helping to shift to negative energy balance, and will promote a greater level of fitness. However, the best exercise program is one that is enjoyable, sustainable, and safe for you; if you're just starting out, it's wise to begin with low- to moderate-intensity activities and work your way up from there.

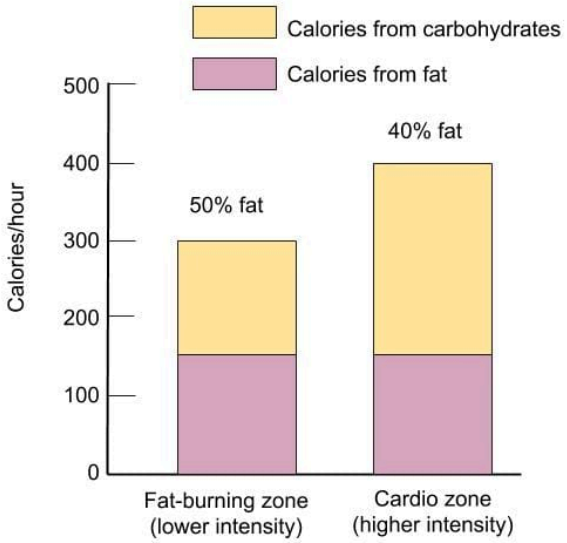


Figure 10.5. The fat-burning zone. While a greater percentage of calories burned in lower intensity exercise come from fat, the overall total calorie burn is greater in higher intensity exercise.

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11.4: Nutrient Needs for Athletes

Nutrition is essential to your performance during all types of exercise. As an athlete, the foods consumed in your diet are used to provide the body with enough energy and specific nutrients to fuel an activity and maximize performance. Athletes have different nutritional needs than the general population in order to support their vigorous activity levels in both practice and competition. On this page, we'll explore the specific nutrient needs of athletes and how they differ from the nutrient needs of less active individuals.



Energy Needs

To determine an athlete's nutritional needs, it is important to revisit the concept of energy metabolism. Energy intake is the foundation of an athlete's diet, because it supports optimal body functions, affects intake of macronutrients and micronutrients, and assists in maintaining body composition. **Energy needs for athletes increase depending on their energy expenditure. The amount of energy expended during physical activity is contingent on the intensity, duration, and frequency of the exercise.** Competitive athletes may need 3,000 to over 5,000 calories daily compared to a typical inactive individual who needs about 2,000 calories per day. Energy needs are also affected by an individual's sex, age, and weight. Weight-bearing exercises, such as running, burn more calories per hour than non-weight-bearing exercises, such as swimming, since weight-bearing exercises require your body to move against gravity. Additionally, men typically burn more calories than women for the same activity, because men have more muscle mass which requires more energy to support and move around.

Macronutrient Needs

The composition of macronutrients in the diet is a key factor in maximizing performance for athletes. As discussed on the previous page, carbohydrates, fat, and protein can all be utilized for energy production during exercise, though the amount utilized of each nutrient varies depending on the intensity and duration of the exercise.

Carbohydrates

Carbohydrates are an important fuel source for the brain and muscle during exercise. Carbohydrate storage in the liver and muscle is relatively limited, and therefore it is important for athletes to regularly consume enough carbohydrates from their diet. Carbohydrate needs should increase about 3-10 g/kg/day depending on the athlete's type and level of training and competition (Table 10.3.).[1]

Table 10.3. Athlete's daily needs for carbohydrate fuel[1]

Activity Level	Example of Exercise	Increase of Carbohydrate (g/kg of athlete's body weight/day)
Light	Low-intensity or skill-based activities	3-5
Moderate	Moderate exercise program (about 1 hour/day)	5-7
High	Endurance program (about 1-3 hours/day of moderate to high intensity exercise)	6-10
Very high	Extreme commitment (4-5 hours/day of moderate to high intensity exercise)	8-12

Fat

Fat is a necessary component of a healthy diet to provide energy and essential fatty acids and to facilitate the absorption of fat-soluble vitamins. Athletes are recommended to consume the same amount of fat in the diet as the general population, 20 to 35% of their energy intake. Although these recommendations are in accordance with public health guidelines, athletes should individualize their needs based on their training level and body composition goals. Fat intakes below 20% of energy intake will reduce the availability of fat-soluble vitamins and essential fatty acids, especially omega-3 fatty acids.

Protein

Although protein accounts for only about 5% of energy expended, dietary protein is necessary to support metabolic reactions that generate ATP, which rely heavily on proteins such as enzymes and transport proteins. Additional protein also helps muscles with maintenance, growth, and repair. For these reasons, athletes have higher protein needs than the general population. It is recommended that athletes consume 1.2 to 2.0 g/kg/day of protein in order to support these functions. Higher intakes may also be needed for short periods of intense training or when reducing energy intake.[1]

It is important to consume adequate amounts of protein and to understand that the quality of the protein consumed affects the amount needed. Complete protein foods such as meats, dairy, and eggs contain all of the essential amino acids in relative amounts that most efficiently meet the body's needs for growth, maintenance, and repair of muscles. Vegetarian diets contain mostly incomplete protein sources, which have lower digestibility and amino acid patterns that do not match human needs as closely as most animal proteins. To compensate for this, vegetarian athletes need to consume more dietary protein than non-vegetarians and should target the upper end of the recommended protein intake.

In addition to the amount and quality of proteins consumed, timing of protein intake has been shown to impact muscle protein synthesis. Studies show that the synthesis of muscle protein is optimized with high quality protein consumption after exercise, ideally 15 to 25 grams of protein in the early recovery phase after a workout (0-2 hours after exercise). A similar amount of protein should be consumed every 3-5 hours, spread out across the day over multiple meals within the 24 hours post-workout, so that amino acids are always available for optimal protein synthesis.[2] One recommended strategy is to aim for 0.4 g/kg/meal across four meals in order to reach 1.6 g/kg/day for muscle synthesis.[3]

Although athletic training increases protein needs, athletes can meet their protein requirement through high quality food sources, and most do not need to consume protein supplements. Here are some examples of snacks or small meals that contain at least 15 to 25 grams of protein[4]:

- ½ cup of granola plus ¼ cup almonds (16 grams protein)
- 7 oz. Greek yogurt (20 grams protein)
- Peanut butter sandwich (20 grams protein)
- 2 scrambled eggs and 1 cup of milk (20 grams protein)
- 3 oz. canned tuna (½ can) with ½ cup crackers (22 grams protein)
- Turkey and cheese sandwich (32 grams protein)



These whole food options have the benefit of coming packaged with other nutrients, including carbohydrates to replenish glycogen stores, fiber, and micronutrients, and are often less costly than most protein supplements. Like all dietary supplements, protein shakes and other supplements are not well-regulated; some contain unnecessary additives such as sweeteners and herbs, and some have been found to contain unsafe levels of heavy metals like arsenic and mercury. Protein supplements do have the benefit of being convenient and shelf-stable. If you choose to use a protein supplement, look for one certified by a third-party testing organization and with a simple ingredient list.[5]

Micronutrient Needs

Vitamins and minerals are essential for energy metabolism, the delivery of oxygen, protection against oxidative damage, and the repair of body structures. When exercise increases, the amounts of many vitamins and minerals needed are also increased. Currently, there are no special micronutrient recommendations for athletes, but most athletes will meet their needs by consuming a balanced diet that meets their energy needs. Because the energy needs of athletes increase, they often meet their higher need for vitamins and minerals through the additional food they consume to meet energy needs. However, athletes who limit energy intake or utilize extreme weight-loss practices may put themselves at risk for vitamin and mineral deficiencies.

Pre-Workout Meals: Fueling the Body for Physical Activity

Good nutrition prior to physical activity (PA) plays a critical role in maximizing performance, maintaining energy levels, and preventing early fatigue. The ideal pre-workout meal should be strategically timed and composed to optimize digestion and energy availability, while minimizing gastrointestinal discomfort during exercise.

Timing and Energy Content

A pre-workout meal should generally be consumed **1 to 4 hours before** engaging in moderate to intense physical activity. The closer the meal is to the start of activity, the smaller and simpler it should be to ensure adequate digestion. The goal is to provide enough energy to support performance without leaving food in the stomach at the onset of activity, which can lead to discomfort, cramping, or nausea.

Energy needs vary depending on body size, metabolic rate, and the intensity and duration of the activity. However, a typical pre-workout meal might provide **200–500 kcal**, with larger meals reserved for earlier timing (e.g., 3–4 hours before PA), and smaller snacks if consumed closer to the start of exercise.

Macronutrient Composition

The most critical macronutrient in the pre-workout meal is **carbohydrate**, especially **complex carbohydrates** such as oats, bread (in moderation), rice, or starchy vegetables. These provide a sustained release of glucose into the bloodstream, supporting energy needs throughout the activity. However, **fiber** content should be kept **low** despite the use of complex carbs. This is because fiber stimulates **peristalsis** — the wave-like intestinal contractions that move food through the digestive tract — which can lead to an urgent need to defecate during physical activity. Additionally, high-fiber foods remain longer in the gastrointestinal tract, which may increase the risk of discomfort or cramping.

Fat should also be minimized in the pre-workout meal, as it slows gastric emptying and prolongs digestion, increasing the likelihood that food will still be in the stomach when activity begins. A full stomach during exercise, particularly during high-intensity or jostling activities (e.g., running, jumping), can impair performance and cause significant gastrointestinal distress.

A **moderate amount of protein** may be included in the pre-workout meal, especially if the individual will not be able to eat again for several hours. However, protein plays a more critical role **post-exercise** in supporting muscle repair and recovery, so it is not the primary macronutrient of concern before activity.

Optional Ergogenic Aid: Caffeine

For individuals seeking a legal and well-studied performance boost, **caffeine** may be included in the pre-workout period. As an **ergogenic aid**, caffeine has been shown to improve endurance by enhancing alertness, reducing perceived exertion, and increasing time to fatigue. The effects of caffeine typically peak **30 to 90 minutes** after ingestion, depending on the form and the individual's metabolism. Caffeine can be consumed via coffee, tea, or supplements; however, it is important to note individual tolerance, as excessive intake can cause jitteriness, increased heart rate, or gastrointestinal upset.

Key Takeaways for Pre-Workout Meals:

- Eat **1–4 hours** before physical activity, depending on meal size.
- Focus on **complex carbohydrates** for sustained energy.
- Keep **fiber and fat low** to promote quick digestion and avoid GI distress.
- Include **moderate protein** if needed, though it's more essential post-exercise.
- Consider **caffeine** as a performance-enhancing aid if appropriate and well-tolerated.

An effective pre-workout meal should fuel the body, empty the stomach in time, and allow the digestive tract to stay quiet — so the athlete can focus entirely on performance.

Post-Workout Meals: Recovery, Rehydration, and Rebuilding

The post-workout meal plays a vital role in the **recovery process** following physical activity (PA). While pre-workout nutrition fuels performance, post-exercise intake supports **muscle repair**, **glycogen replenishment**, and **overall recovery**. The timing and composition of this meal directly influence how quickly and effectively the body recovers and adapts to the stress of exercise.

Timing: The Anabolic Window

Nutrient timing is especially important post-exercise. The body enters a state of heightened **insulin sensitivity** and increased nutrient uptake during the period immediately following PA—often referred to as the **anabolic window**. Ideally, individuals should consume a post-workout meal or snack **within 30 to 60 minutes** after completing exercise. This window is particularly important after intense or prolonged activity, or when recovery time between sessions is short (e.g., two-a-day workouts or back-to-back competitions).

Macronutrient Composition

An ideal post-workout meal includes:

1. **Carbohydrates**
   Carbohydrates are essential for **replenishing glycogen stores** depleted during activity, especially after endurance or high-intensity exercise. The amount needed depends on the intensity and duration of the workout, but a general guideline is **1.0–1.5 g of carbohydrate per kilogram of body weight** within the first hour post-exercise. Both **simple** and **complex carbohydrates** can be used post-workout, as quick digestion is no longer a concern.

2. **Protein**
   Protein intake is crucial post-exercise to stimulate **muscle protein synthesis (MPS)** and support the repair and growth of muscle tissue. A post-workout meal should contain **15–30 grams of high-quality protein**, depending on the individual's size, training intensity, and goals. Ideal sources include lean meats, dairy, eggs, legumes, or protein supplements containing complete amino acid profiles (e.g., whey protein). Combining protein with carbohydrates also enhances glycogen replenishment and anabolic recovery.

3. **Fluids and Electrolytes**
   Rehydration is another essential component of recovery. Individuals should aim to replace **150% of the fluid lost** during exercise over the next few hours, particularly if the session involved heavy sweating. Including **sodium** and other electrolytes in the recovery plan (either through food or sports drinks) can help restore fluid balance and prevent dehydration-related fatigue.

4. **Fat (Optional and Minimal)**
   While **dietary fat** is not inherently harmful post-workout, it is **not a priority nutrient** during the recovery window. Small amounts of fat are acceptable and may help with satiety and nutrient absorption, but high-fat meals should be avoided immediately post-exercise, as they may slow gastric emptying and nutrient absorption.

Additional Considerations

- For athletes training multiple times per day or in energy-demanding sports, **frequent, carbohydrate- and protein-rich meals or snacks** are critical to maintain performance and support adaptation.

- Individuals with limited appetite post-exercise may benefit from **liquid recovery options**, such as smoothies or shakes, which are easier to consume and digest.

Key Takeaways for Post-Workout Nutrition:

- Eat within **30–60 minutes** post-exercise to maximize recovery.
- Prioritize **carbohydrates** (1.0–1.5 g/kg) to replenish glycogen stores.
- Include **15–30 g of high-quality protein** to support muscle repair.
- **Rehydrate** with fluids and electrolytes to restore balance.
- Keep **fat intake minimal** during the recovery window.

Effective post-workout nutrition ensures that the hard work put into training yields optimal results — better performance, faster recovery, and reduced risk of injury or overtraining.

A Word on Dietary Supplements and Ergogenic Aids

Many athletes consider taking dietary supplements or ***ergogenic aids* (i.e., substances used to enhance performance)** in an effort to improve performance, increase energy levels, or make up for poor nutrition choices. However, it is important to remember that supplements and ergogenic aids are not regulated, leading to frequent use of false advertising and unsubstantiated claims by the supplement industry. Athletes must be careful not only in deciphering the claims of products, but also in researching their safety and efficacy, particularly in relation to any rules and regulations that govern the sport in which the athlete participates. Very

few supplements that claim to have ergogenic benefits have sound evidence to back up those claims, and in some situations, consuming them could be dangerous. Most athletes can meet their nutrition needs without added supplements. Athletes who have nutrition concerns should consult with a sports dietitian or other sport science professional to make sure their individual needs are met safely.

Table: Commonly Used Ergogenic Aids — Claims vs. Evidence

Supplement / Aid	Purported Benefit	What the Evidence Shows	Safety Concerns	Other Notes
Creatine Monohydrate	Increases strength, power, lean muscle mass; enhances high-intensity performance	**Well-supported** for improving short bursts of power and repeated high-intensity efforts (e.g., weightlifting, sprinting)	Generally safe when used as directed; minor weight gain (water retention) common	Best researched form is **creatine monohydrate**; requires consistent daily intake (3–5 g/day for maintenance)
Caffeine	Increases alertness, endurance, and reduces perceived exertion	**Strong evidence** for enhancing endurance performance and delaying fatigue	Can cause jitteriness, GI upset, increased heart rate, or insomnia; sensitive individuals should limit intake	Effects peak ~30–90 minutes post-ingestion; common dose is **3–6 mg/kg body weight**
Branched-Chain Amino Acids (BCAAs)	Stimulate muscle growth, reduce fatigue, prevent muscle soreness	**Limited evidence**; no added benefit if adequate protein is consumed in the diet	Generally safe, but unnecessary for most individuals	Complete protein sources (e.g., whey) are more effective and cost-efficient
Beta-Alanine	Improves muscular endurance and reduces fatigue during high-intensity exercise	**Some support** for increasing buffering capacity in muscles, especially during anaerobic exercise	May cause **paresthesia** (tingling sensation); long-term safety not fully established	Most effective when taken daily for several weeks
Nitric Oxide Boosters (e.g., beetroot juice, L-arginine)	Increase blood flow to muscles, improve endurance	**Inconclusive**; some evidence for beetroot juice (dietary nitrates), but **L-arginine largely ineffective**	Generally safe in dietary form; excessive supplementation may cause GI distress	Individual responses vary; benefits may depend on baseline fitness level
HMB (Beta-hydroxy beta-methylbutyrate)	Preserves muscle mass during intense training or caloric restriction	**Limited evidence**; may help in untrained individuals or in clinical populations, but minimal benefit in trained athletes	Likely safe; long-term effects not well studied	Expensive compared to alternatives like dietary protein
Glutamine	Enhances recovery, immune support, and reduces muscle soreness	**No strong evidence** for performance or recovery benefits in healthy individuals	Generally safe; may be beneficial during illness or for clinical use	Often marketed based on weak or outdated data
Testosterone Boosters (e.g., tribulus terrestris, D-aspartic acid)	Increase muscle mass, strength, and testosterone levels	**No credible evidence** for performance enhancement in healthy individuals	Potential endocrine disruption; unregulated products may contain banned substances	Often mislabeled or adulterated; **not recommended**
Fat Burners / Thermogenics (e.g., synephrine, green tea extract)	Enhance fat loss and metabolism	**Minimal evidence** for meaningful fat loss; effects are modest and short-lived	Some ingredients may raise blood pressure or heart rate; risk of stimulant overload	May be banned by sport organizations; not a substitute for diet/exercise

Supplement / Aid	Purported Benefit	What the Evidence Shows	Safety Concerns	Other Notes
Anabolic Steroids (illicit or prescribed)	Dramatically increase muscle mass and strength	**Highly effective**, but with **severe health risks**	Illegal without prescription; liver damage, hormonal imbalance, cardiovascular issues, psychological effects	**Banned by all sports organizations**; unethical and dangerous

Key Takeaways:

- ***Most ergogenic aids are ineffective and some cause harm***
- **Creatine monohydrate** and **caffeine** are the most **reliable and well-researched ergogenic aids** for athletic performance.
- Many other supplements **lack sufficient evidence** or are **ineffective** when a balanced diet is already in place.
- Always evaluate **safety, legality (in sport), and individual variability** before using any ergogenic aid.
- Athletes should consult with a **registered dietitian nutritionist or sports physician** before starting any supplement regimen.

Water and Electrolyte Needs

During exercise, being appropriately hydrated contributes to performance. Water is needed to cool the body, transport oxygen and nutrients, and remove waste products from the muscles. Water needs are increased during exercise due to the extra water losses through evaporation and sweat. Dehydration can occur when there are inadequate water levels in the body and can be very hazardous to the health of an individual. As the severity of dehydration increases, the exercise performance of an individual will begin to decline (see Figure 10.6). It is important to continue to consume water before, during, and after exercise to avoid dehydration as much as possible.

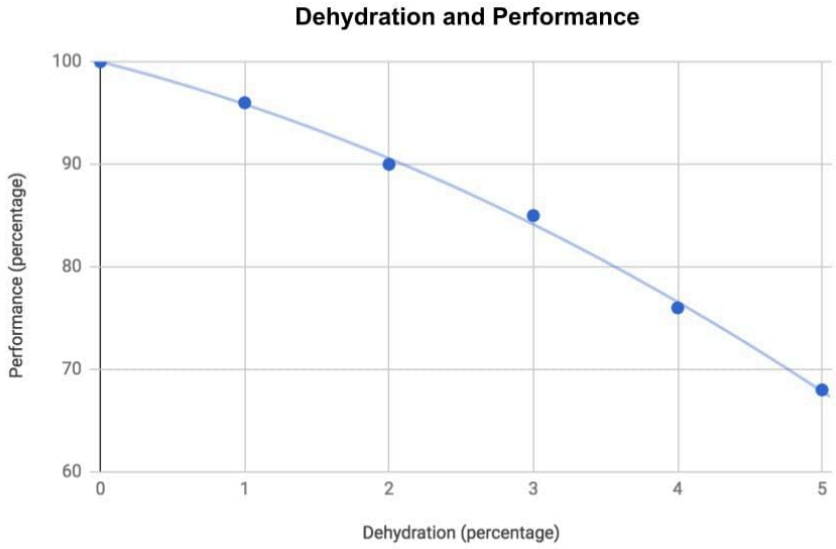


Figure 10.6. The effect of dehydration on exercise performance.

During exercise, thirst is not a reliable short-term indicator of the body's water needs, as it typically is not enough to replace the water lost. Even with constant replenishing of water throughout a workout, it may not be possible to drink enough water to compensate for the losses. Dehydration occurs when water loss is so significant that total blood volume decreases, which leads to a reduction in oxygen and nutrients transported to the muscle cells. A decreased blood volume also reduces blood flow to the skin and the production of sweat, which can increase body temperature. As a result, the risk of heat-related illnesses such

as heat exhaustion or heat stroke, increases. The external temperature during exercise can also play a role in the risk of heat-related illnesses. As the external temperature increases, it becomes more difficult for the body to dissipate heat. As humidity also increases, the body is unable to cool itself through evaporation.

Hyponatremia and Sports Drinks



Sweating during exercise helps our bodies to stay cool. Sweat consists of mostly water, but it also causes losses of sodium, potassium, calcium and magnesium. During most types of exercise, the amount of sodium lost is very small, and drinking water after a workout will replenish the sodium in the body. However, during long endurance exercises, such as a marathon or triathlon, sodium losses are larger and must be replenished. If water is replenished without sodium, the sodium already in the body will become diluted. These low levels of sodium in the blood will cause a condition known as hyponatremia. When sodium levels in the blood are decreased, water moves into cells through osmosis, which causes swelling. Accumulation of fluid in the lungs and the brain can cause serious, life-threatening conditions such as seizure, coma, and death (see Unit 9).

In order to avoid hyponatremia, athletes should increase their consumption of sodium in the days leading up to an event and consume sodium-containing sports drinks during their race or event. A well-concocted sports drink contains sugar, water, and sodium in the correct proportions so that hydration is optimized. The sugar is helpful in maintaining blood-glucose levels needed to fuel muscles, the water keeps an athlete hydrated, and the sodium enhances fluid absorption and replaces some of that lost in sweat. The American College of Sports Medicine states that the goal of drinking fluids during exercise is to prevent dehydration, which compromises performance and endurance.

Homemade Sports Drink

Note: The nutrition profile of commercial sports drinks is 50 to 70 calories per 8 ounces, with about 110 milligrams of sodium. Following is a simple recipe that offers this profile, but at a much lower cost than expensive store-bought brands—without additives, colors, or preservatives.

Ingredients:

¼ cup (50 g) sugar

¼ teaspoon salt

¼ cup (60 ml) water

¼ cup (60 ml) orange juice (not concentrate) plus 2 tablespoons lemon juice

3 ½ cups (840 ml) cold water

Method:

1. In the bottom of a pitcher, dissolve the sugar and salt in the hot water.
2. Add the juice and the remaining water; chill.
3. Quench that thirst!

Yield: 1 quart (1 L)

Nutrition Information: 200 total calories; 50 calories per 8 ounces (240 ml); 12 g carbohydrate; 110 mg sodium

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

Who Needs Sports Drinks?

Scientific studies show that, under certain circumstances, consuming sports drinks (instead of plain water) during high-intensity exercise lasting longer than one hour significantly enhances endurance, and some evidence also indicates it enhances performance. There is no consistent evidence that drinking sports drinks instead of plain water enhances endurance or performance in individuals exercising less than one hour at a time and at low to moderate intensities. Children and adult athletes exercising for more than one hour at high-intensity (tennis, rowing, rugby, soccer, etc.) may benefit from consuming a sports drink rather than water. However, consuming sports drinks provides no benefit over water to endurance, performance, or exercise recovery for those exercising less than an hour. In fact, as with all other sugary drinks containing few to no nutrients, they are only another source of calories. Drinking sports drinks when you are doing no exercise at all is not recommended.

Self-Check:

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11.5: Nutrition-Relevant Concerns in Sports Performance

Athletes are not immune to nutrition-related risks: when energy intake, micronutrient status, hydration, or recovery do not match the demands of training, serious health and performance problems can emerge. The following section examines a range of such conditions — from the formerly defined Female Athlete Triad (now understood more broadly as Relative Energy Deficiency in Sport, or RED-S) to foot-strike hemolysis, sports anemia, dehydration, electrolyte imbalance, and overtraining syndrome — highlighting their causes, consequences and nutritional implications.

'Female Athlete Triad' / RED-S

Historically, the Female Athlete Triad referred to the coexistence of disordered eating (or inadequate energy intake), menstrual dysfunction such as amenorrhea or oligomenorrhea, and low bone mineral density (osteopenia or osteoporosis), most often observed in female athletes striving for a lean physique. This framework, first described in the early 1990s, emphasized three interrelated clinical problems and was especially noted in sports that promote leanness, aesthetics, or weight-class restrictions — such as distance running, gymnastics, ballet, figure skating, diving, and endurance swimming.

Contemporary understanding, however, has expanded significantly. The International Olympic Committee (IOC) now uses the term Relative Energy Deficiency in Sport (RED-S) to describe a broader syndrome that stems from low energy availability (EA) and affects multiple body systems; importantly, RED-S can occur in male as well as female athletes. This wider lens reflects observations in a greater variety of sports, including cycling, rowing, triathlon, lightweight rowing, wrestling, martial arts, and other disciplines where high training loads, aesthetic pressures, or weight-category rules increase the risk of under-fueling.

RED-S develops when energy intake fails to meet total energy expenditure, which includes training demands, metabolic needs, and the energy required for daily living. This chronic energy deficit disrupts a wide range of physiological functions — not only menstrual and bone health but also metabolic rate, immune function, cardiovascular health, protein synthesis, and overall recovery capacity. Hormonal changes often accompany these disruptions, including decreases in estrogen, thyroid hormones, insulin-like growth factor-1 (IGF-1), and other metabolic regulators. These alterations contribute to impaired bone turnover, compromised bone mineralization, and increased vulnerability to skeletal injury.

Nutrient deficiencies frequently accompany low energy availability. Inadequate intake of protein, calcium, vitamin D, iron, and other nutrients can further weaken bone health, diminish physiological resilience, and exacerbate the systemic effects of RED-S. Clinically, identifying RED-S can be challenging because not all three classical components of the original Female Athlete Triad need to be present. Early signs — such as subtle menstrual irregularity, unexplained fatigue, decreased performance, recurrent injuries, or stress fractures—should prompt further evaluation.

Early detection and timely intervention are critical. Restoring adequate energy intake, improving dietary quality, and modifying training loads can prevent or reverse many long-term consequences of RED-S, including impaired bone health, increased fracture risk, hormonal disturbances, immune dysfunction, and declining athletic performance. The inclusion of both female and male athletes across a wide variety of sports in the current RED-S framework underscores the importance of broad awareness, consistent monitoring, and proactive nutrition support for any athlete engaging in high-volume or high-intensity training.

Implications for nutrition practice: Athletes should maintain sufficient caloric intake to match energy expenditure. Regular monitoring (periodic health evaluations), attention to dietary quality (adequate macro- and micronutrients), and awareness of signs such as unexplained fatigue, menstrual irregularities, frequent injuries or stress fractures, delayed recovery — should be part of preventive nutrition support.

Foot-strike hemolysis

Foot-strike hemolysis — also known as “march hemoglobinuria” or “runner’s hemolysis” — refers to the repeated destruction of red blood cells during continuous, high-impact activities such as long-distance running, where mechanical forces on the feet lead to RBC rupture. Laboratory indicators may include elevated free hemoglobin, decreased haptoglobin, increased reticulocyte counts, and rises in hemolysis-related markers such as lactate dehydrogenase and unconjugated bilirubin. Although these signs confirm that hemolysis occurs, a recent 2024 scoping review found that the degree of RBC destruction is generally modest, with

many endurance athletes maintaining normal hemoglobin and hematocrit levels. This pattern suggests that foot-strike hemolysis may contribute to the broader phenomenon of sports anemia, addressed further below, but it is unlikely to be the sole cause and instead represents one mechanism among several. From a nutritional perspective, recognizing its role highlights the importance of monitoring iron status — because RBC destruction increases iron turnover — and ensuring that athletes consume sufficient iron and overall nutrients to support red blood cell production and prevent depletion.

Sports anemia

"Sports anemia" is a term broadly used to describe the lower hemoglobin and hematocrit values often observed in athletes — particularly those involved in endurance sports — compared to sedentary individuals. The phenomenon is complex and multifactorial, with contributing mechanisms including expanded plasma volume, which can create a dilutional or "pseudo-anemia," increased iron losses through sweat, gastrointestinal bleeding, heavy menstruation, or hemolysis, inadequate dietary iron intake relative to heightened physiological demands, and reduced iron absorption, for example due to inflammation-induced upregulation of hepcidin after exercise.

A 2024 meta-analysis of 17,519 athletes worldwide reported that approximately 53.9% of student-athletes exhibited low ferritin (hypoferritinemia), and 23% had absolute iron deficiency (ferritin < 20 µg/L), even if not all were anemic. Evidence indicates that iron deficiency can directly affect performance: a 2024 study of competitive athletes found that those with iron deficiency had lower maximal oxygen uptake (VO_2 peak) than their iron-replete counterparts. Historical data from elite runners and triathletes (2009–2015) show that iron deficiency, and in some cases iron-deficient anemia, was prevalent, with around 60% of female triathletes and 56% of female runners experiencing at least one episode of iron deficiency, occasionally with hemoglobin values below standard thresholds. Importantly, iron deficiency can impair endurance performance even in the absence of overt anemia, as iron is essential not only for hemoglobin synthesis and oxygen transport but also for myoglobin formation, mitochondrial function, and overall energy metabolism.

Implications for nutrition practice: Regular monitoring of iron status (ferritin + hemoglobin + other relevant markers) in endurance and high-load athletes; ensuring sufficient dietary iron (heme iron if diet allows, or well-absorbed non-heme iron plus absorption enhancers like vitamin C); adjusting iron intake to match increased losses; and assessing other contributing factors (training load, hemolysis, menstruation, gastrointestinal losses, inflammation) rather than assuming all cases of low hemoglobin reflect simple "sports anemia."

Other nutrition-linked issues: dehydration, electrolyte imbalance, & overtraining syndrome

Dehydration and electrolyte imbalance: Adequate fluid and electrolyte balance is critical for athletic performance. Even a small body-mass loss (> ~2%) due to dehydration can impair endurance, strength, power output, thermoregulation, cognitive function and increase risk of heat illness.

- Overdrinking (too much fluid without proper electrolyte replacement) can also cause problems: in endurance events, excessive water intake without sodium can lead to Exercise-Associated Hyponatremia (EAH) — a dangerous condition with symptoms ranging from nausea and headaches to seizures and loss of consciousness, and even death.

- Imbalanced sodium (or other electrolytes like potassium, magnesium) may contribute to muscle cramps, weakness, impaired nerve and muscle function, poor recovery, and reduced performance.

Overtraining syndrome / chronic under-fueling / poor recovery: When athletes chronically under-fuel (low energy availability), neglect recovery, or engage in extreme weight-control behaviors (e.g., dehydration, dieting, saunas), they risk long-term consequences — including impaired muscle function, reduced performance, increased injury risk, hormonal disturbances, delayed growth or maturation (in younger athletes), poor bone development, or immune dysfunction.

- Nutrient deficiencies beyond iron — e.g., inadequate protein, calcium, vitamin D, or other micronutrients — can compound these problems, especially for bone health, recovery, immune function, and overall performance.

Implications for nutrition practice: Athletes — especially those participating in endurance sports or high training volume —

should be supported with individualized hydration and electrolyte strategies (not one-size-fits-all), periodic assessment of fluid status, and thoughtful attention to recovery, nutrient density, and overall energy balance. Weight-control behaviors (sweat-suits, saunas, diuretics, extreme dieting) should be discouraged.

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CHAPTER 12: NUTRITION DURING PREGNANCY AND THE FIRST 1000 DAYS

Learning Objectives

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

- Describe the physiological basis for nutrient requirements from pregnancy through the toddler years.

12.1: Introduction to Nutrition Throughout the Lifecycle
12.2: Nutrition during Pregnancy
12.3: Nutrition for Lactation in Early Infancy
12.4: More on nutrition in the first 6 months of life
12.5: Nutrition in Later Infancy and Toddlerhood

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12.1: Introduction to Nutrition Throughout the Lifecycle

Throughout all of the seasons of life, food is a basic human need. That's just as true for a newborn infant filling her tiny tummy with breast milk as it is for her mother, whose body is performing the physiological feat of synthesizing milk for her baby. And it's equally true for her grandparents, who are preparing a meal to share with the new family once they come home from the hospital. Food nourishes our bodies in every stage of life, but eating together is also a way of nurturing our social and emotional connections with one another.



Figure 12.1.1: "Grandpa's Arms" photo by Johnny Cohen on Unsplash (license information)

Yet, as we grow and change, so do our nutrient needs, and every stage of life brings unique challenges.

People of all ages need the same basic nutrients—essential amino acids, carbohydrates, essential fatty acids, and twenty-eight vitamins and minerals—to sustain life and health. However, the amounts of nutrients needed differ. Throughout the human life cycle, the body constantly changes and goes through different periods known as stages. The next two chapters in the textbook will cover Nutrition Throughout the Lifecycle. This chapter (12) will focus on pregnancy, lactation and infancy. Chapter 13.1 will focus on childhood through adolescence and Chapter 13.1 will focus on the stages of adulthood. The major stages of the human life cycle are defined as follows:

- **Pregnancy.** The development of a zygote into an embryo and then into a fetus in preparation for childbirth.
- **Infancy.** The earliest part of childhood. It is the period from birth through the first birthday.
- **Toddler years.** Occur during ages one to three and are the end of early childhood.
- **Childhood.** The period from birth to eighteen.
- **Onset of Puberty.** Can occur from ages nine to fourteen, which is the beginning of adolescence.
- **Older adolescence.** The stage that takes place between ages fourteen and eighteen.
- **Adulthood.** The period from the end of adolescence to the end of life and starts at age 20 y, although legal definitions of adulthood differ by country.
- **Middle age.** The period of adulthood that stretches from age forty-five to sixty-four.
- **Senior years, or old age.** Extend from age sixty-five until the end of life.

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12.2: Nutrition during Pregnancy



Becoming a parent is a huge commitment, and for all its many rewards, it's also costly to have a baby. And that cost comes not just in time and money. For mothers, having a baby also represents a nutritional and metabolic investment. Throughout pregnancy and infancy, a new human grows and develops, and this feat is made possible in large part because of the nutrients that the mother provides. Requirements for many nutrients are greater in pregnancy and lactation to support maternal health, the healthy growth and development of the fetus, and the production of milk to nourish the infant.

Physiology of Pregnancy

Human pregnancy lasts for approximately 40 weeks (when counted from the first day of a woman's last menstrual period) and is roughly divided into thirds, or trimesters. Dramatic changes occur throughout pregnancy, including in the earliest days, sometimes before women realize they're pregnant. Therefore, adequate nutrition is vital for women who are trying to conceive or may become pregnant. In addition, women who are either underweight or obese before becoming pregnant can find it more difficult to get pregnant and face greater risks of pregnancy complications. Therefore, it's recommended to establish healthy eating and exercise habits and work towards a healthy weight before pregnancy. [1] Nutrition before conception is also important for fathers; studies have shown that sperm quality is better in fathers who have a healthy body weight, consume adequate amounts of folate and omega-3 fatty acids, and follow a healthy dietary pattern, such as a Mediterranean diet emphasizing seafood, poultry, whole grains, legumes, and fruits and vegetables. [2]

Pregnancy begins when the sperm fertilizes the egg, and the single cell formed from this union begins to divide and differentiate. During the first few weeks of development, the cells of the uterine lining provide nutrients to the developing embryo. Between the 4th and 12th weeks, the developing ***placenta*** gradually takes over the role of feeding the embryo, which is called a fetus beginning in the 9th week of pregnancy. **The placenta forms from tissues deriving from both the fetus and the mother, and this new organ becomes the interface between the two. The placenta provides nutrition and respiration, handles waste from the fetus, and produces hormones important to maintaining the pregnancy.** The blood of the fetus and mother do not mix in the placenta, but they come close enough that nutrients (including glucose, amino acids, fatty acids, vitamins, and minerals) and oxygen can pass from the mother's blood to the fetus, and carbon dioxide and waste products can be passed from the fetus to the mother. [3]

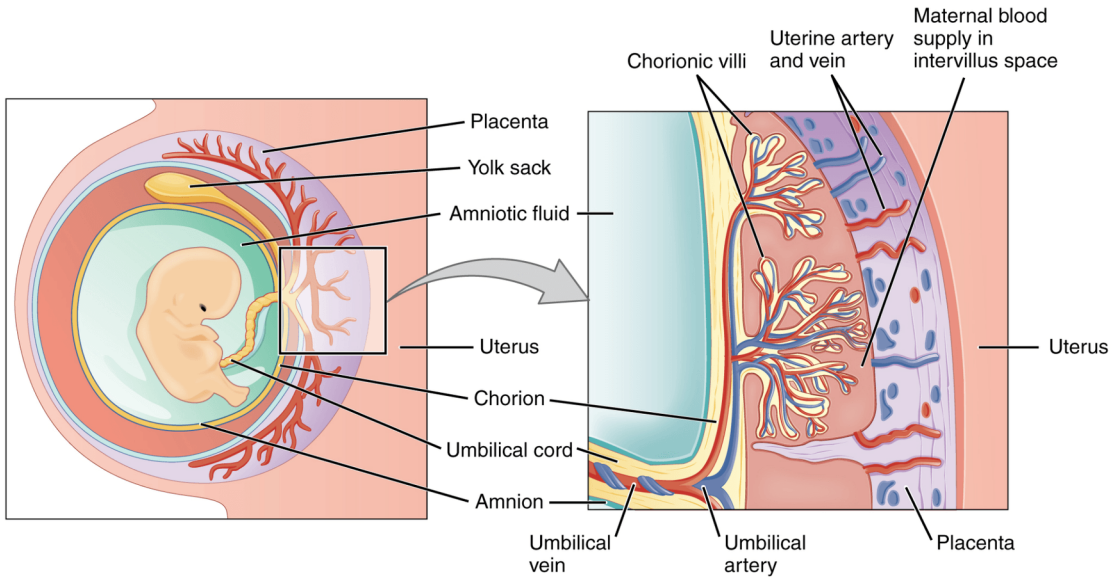


Figure 11. 1. Cross-section of the placenta. In the placenta, the maternal and fetal bloodstreams do not mix, but nutrients, gasses, and waste products can diffuse between them.

The first trimester is a key period for the formation of embryonic and fetal organs. During the second and third trimesters, the fetus continues to grow and develop, with final development of organs such as the brain, lungs, and liver continuing in the last few weeks of pregnancy. Infants born before 37 weeks of pregnancy are considered preterm, and because they have not completed fetal development, are at increased risk for a range of health problems. Advances in neonatal care have greatly improved outcomes for these babies born too soon, but in most cases, the best scenario is for the fetus to have the full term of pregnancy to develop in the protective environment of the uterus, receiving nutrients through the placenta. [4]

Nutrient Requirements During Pregnancy

Pregnant women need more calories, macronutrients, and micronutrients than they did before pregnancy. However, the increase in nutrient requirements is relatively greater than the increase in caloric needs, emphasizing the importance of a nutrient-dense diet . A dietary pattern focused on vegetables, fruits, whole grains, nuts, legumes, fish, and vegetable oils, and lower in red and processed meats, refined grains, and added sugars is associated with a reduced risk of pregnancy complications such as gestational diabetes and hypertension. [5] There is nothing revolutionary about this dietary pattern—it's what is recommended for everyone! However, it's even more beneficial during pregnancy, as it promotes both maternal and fetal health.

Energy Intake and Weight Gain

During the first trimester, energy requirements are generally not increased, so women should consume about the same number of calories as they did before pregnancy. As fetal growth ramps up, energy requirements increase by about 340 calories per day in the second trimester and 450 calories per day in the third trimester. This is just an average; individual energy requirements vary depending on factors such as activity level and body weight before pregnancy . [6-7]

Weight gain is a normal part of pregnancy. The growth of the fetus accounts for about 6 to 8 pounds of weight gain by the end of the pregnancy. Much of the rest comes from the development and expansion of tissues and fluids to support the pregnancy, including the placenta, uterus, breasts, amniotic fluid, blood, and maternal body fluids. In addition, women starting pregnancy at a normal weight should gain about 8 to 10 pounds of body fat and protein during pregnancy, in part to prepare for lactation. [3]

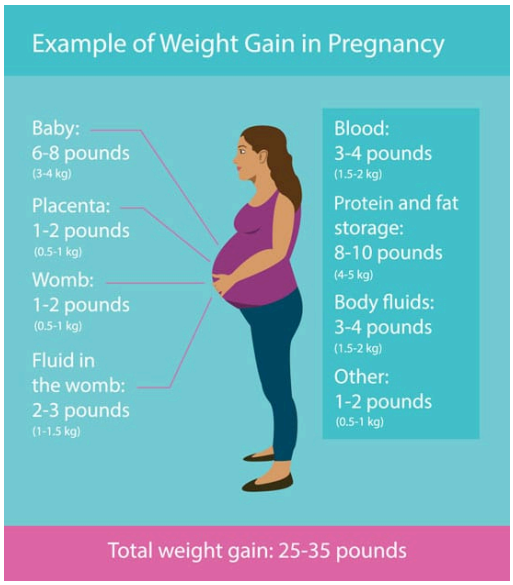


Figure 11.2. Components of weight gain in healthy pregnant women with normal BMI before pregnancy. Weight gain comes not just from the baby, but from many different body systems changing to support the pregnancy.

The Institute of Medicine recommends different amounts of weight gain in pregnancy depending on pre-pregnancy BMI. Women who were underweight before pregnancy need to gain more, and those who were overweight or obese before pregnancy need to gain less. Gaining too little weight in pregnancy can compromise fetal growth, leading to the baby being born too small, which can cause increased risk of illness, difficulty feeding, and developmental delays. Gaining too much weight in pregnancy can cause the baby to be too big at birth, leading to birth complications and increasing the risk of needing a cesarean birth. It can also make it more difficult to lose weight after pregnancy. [8]

Prepregnancy Weight Category	**Body Mass Index (BMI)**	**Recommended Range of Total Weight Gain (lb)**	**Recommended Rates of Weight Gain in the 2nd and 3rd Trimesters (lb/wk)**
Underweight	Less than 18.8	28-40	1 (1-1.3)
Normal weight	18.5-24.9	25-35	1 (0.8-1)
Overweight	25-29.9	15-25	0.6 (0.5-0.7)
Obese	30 and greater	11-20	0.5 (0.4-0.6)

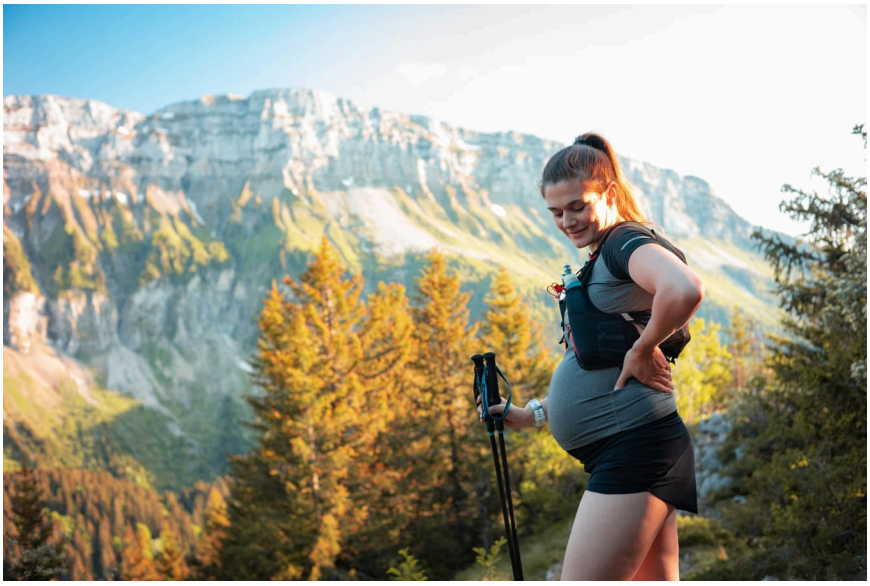
Table 11.1. Recommended weight gain during pregnancy depends on prepregnancy BMI. [7]

Exercising during pregnancy can promote the health of both the mother and the baby. According to the American College of Obstetricians and Gynecologists, regular exercise in pregnancy can reduce back pain, ease constipation, reduce risk of excessive weight gain, improve overall fitness, and help with weight loss after the baby is born. It may also decrease the risk of gestational diabetes, preeclampsia, and cesarean delivery. ACOG recommends that pregnant women get at least 150 minutes of moderate-intensity aerobic activity each week.

Many forms of exercise are safe in pregnancy. Regular exercise of moderate intensity, about thirty minutes per day most days of

the week, keeps the heart and lungs healthy. Healthy women who already participate in vigorous activities before pregnancy, such as running, can continue doing so during pregnancy provided they discuss an exercise plan with their physicians.

However, pregnant women should avoid activities that could cause injury, such as soccer, football, and other contact sports, or activities that could lead to falls, such as horseback riding and downhill skiing. It might also be best for pregnant women not to participate in certain sports, such as tennis, that require her to jump or change direction quickly. Women should consult their healthcare provider for individualized advice about exercising while pregnant. [9]



Macronutrient Requirements

The Acceptable Macronutrient Distributions Ranges (AMDR) for macronutrients are the same for all healthy adults, pregnant or not, with about 45 to 65 percent of calories coming from carbohydrates, 20 to 35 percent from fats, and 10 to 35 percent from protein. As energy intake increases, a pregnant woman needs more of each of these macronutrients.

The RDA for carbohydrates increases from 130 grams per day for non-pregnant adults to 175 grams per day for pregnant women. This level of carbohydrate intake provides energy for fetal development and ensures adequate glucose for both the mother's and the fetus's brain. The recommended fiber intake in pregnancy, expressed as an AI, is the same as for all adults: 14 grams of fiber per 1,000 calories consumed. As caloric intake increases during pregnancy, so should fiber intake, emphasizing the importance of choosing whole food sources of carbohydrates.

Additional protein is also needed during pregnancy. Protein builds muscle and other tissues, enzymes, antibodies, and hormones in both the mother and the fetus, as well as supporting increased blood volume and the production of amniotic fluid. The RDA for protein during pregnancy is 1.1 grams per kg body weight per day, coming to about 71 grams per day for an average woman—roughly 25 grams more than needed before pregnancy. [1]

There is not a specific RDA for fat during pregnancy. Fats should continue to make up 25 to 35 percent of daily caloric intake, providing energy and essential fatty acids (linoleic acid and alpha-linolenic acid), as well as helping with fat-soluble vitamin absorption. The omega-3 polyunsaturated fatty acids DHA and EPA become more important during pregnancy and lactation, because they are essential for brain and eye development of the fetus and infant. The Dietary Guidelines for Americans recommend that pregnant women consume 8 to 12 ounces of seafood each week, in part to provide omega-3 fatty acids. Fish with high levels o f mercury should be avoided; these include king mackerel, marlin, orange roughy, shark, swordfish, tilefish, and bigeye tuna. [11-12]



Figure 11.3. Advice from the EPA and FDA about choosing safe fish to consume during pregnancy and breastfeeding.

Consider the following recommendations for healthy eating during pregnancy, as summarized in the My Pregnancy Plate graphic:

- Choose large portions of a variety of non-starchy vegetables such as leafy greens, broccoli, carrots, bell peppers, tomatoes, mushrooms, and cabbage.
- Choose a variety of whole fruits, limiting juice and dried fruit.
- Aim for 2 to 3 servings of nonfat or 1 percent milk or yogurt (unsweetened or slightly sweetened).
- Choose protein sources like poultry, beans, nuts, eggs, tofu, and cheese. Aim for 8 to 12 ounces of low-mercury seafood each week.
- Choose fiber-rich sources of carbohydrates, including whole grains, legumes, and starchy vegetables such as sweet potatoes and squash.
- Drink mainly water, decaf coffee, or tea. (Caffeine is discussed below).

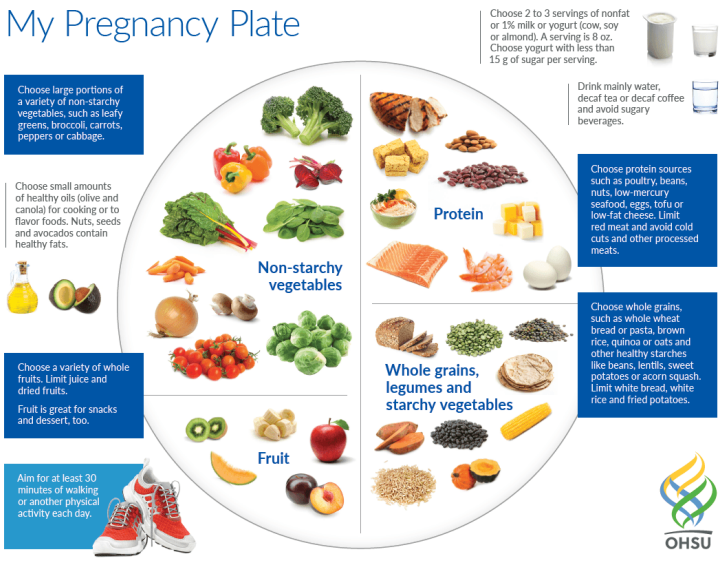


Figure 11.4. The My Pregnancy Plate graphic summarizes dietary recommendations for pregnancy. Source: Created by Christie Naze, RD, CDE, ©Oregon Health & Science University, used with permission.

Vitamin and Mineral Requirements

The physiological demands of pregnancy increase the requirement for many vitamins and minerals. These requirements can be met from food sources, but obstetricians also generally recommend that women take a prenatal supplement while trying to conceive and during pregnancy. This ensures that nutrient requirements are met, while also providing a little peace of mind if pregnancy-related nausea and vomiting limit dietary variety and quality. [1]

The following table compares the recommended intake levels of some vitamins and minerals to the levels needed in pregnancy.

Nutrient	**RDA/AI, Nonpregnant Adult Women**	**RDA/AI, Pregnant Adult**	**Importance**
Vitamin A	700 mcg	770 mcg	*Forms healthy skin and eyesight; helps with bone growth*
Vitamin B6	1.3 mg	1.9 mg	*Helps form red blood cells; helps the body metabolize macronutrients*
Vitamin B12	2.4 mcg	2.6 mcg	*Maintains nervous system; helps form red blood cells*
Vitamin C	75 mg	85 mg	*Promotes healthy gums, teeth, and bones*
Vitamin D	600 IU	600 IU	*Builds fetal bones and teeth; promotes healthy eyesight and skin*
Folate	400	600	*Helps prevent neural tube defects; supports growth and development of fetus and placenta*
Calcium	1,000 mg	1,000 mg	*Builds strong bones and teeth*
Iron	18 mg	27 mg	*Helps red blood cells deliver oxygen to fetus*
Iodine	150 mcg	220 mg	*Essential for healthy brain development*
Choline	425 mg	450 mg	*Important for development of fetal brain and spinal cord*

Table 11.2. Recommended Micronutrient intakes during pregnancy. Sources: The American College of Obstetricians and Gynecologists and the NIH Office of Dietary Supplements .

Among the micronutrients, folate, iron, and iodine deserve a special mention. Folate is essential for the growth and specialization of cells of the central nervous system (see Unit 9). Mothers who are folate-deficient during pregnancy have a higher risk of having a baby with a neural tube birth defect such as spina bifida. Folic acid fortification of grains in the U.S. has helped to raise folate intake in the general population and has reduced the incidence of neural tube defects. However, dietary intake is often not adequate to meet the requirement of 600 mg folate per day in pregnancy, and the American College of Obstetricians and Gynecologists recommends that pregnant women take an additional 400 mg of folic acid each day, an amount usually included in prenatal supplements. [13] The neural tube closes by day 28 of pregnancy, before a woman may realize she is pregnant, so it's important to consume adequate folate while trying to conceive. Because about 45 percent of pregnancies in the U.S. are unplanned, a folic acid supplement is a good idea for anyone who may become pregnant. [14]

Tools for Change

A pregnancy may happen unexpectedly. Therefore, it is important for all women of childbearing age to get 400 micrograms of folate per day prior to pregnancy and 600 micrograms per day during pregnancy. Folate, which is also known as folic acid, is crucial for the production of DNA and RNA and the formation of cells. A deficiency can cause megaloblastic anemia, or the development of abnormal red blood cells, in pregnant women. It can also have a profound 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 spinal cord, and adequate folate reduces the risk of brain abnormalities and neural tube defects, which occur in one in a thousand pregnancies in North America each year. This vital nutrient also supports the spinal cord and its protective coverings. Inadequate folic acid can result in birth defects, such as spina bifida, which is the failure of the spinal column to close. The name "folate" is derived from the Latin word folium for leaf, and leafy green vegetables such as spinach and kale are excellent sources of it. Folate is also found in legumes, liver, and oranges. Additionally, since 1998, food manufacturers have been required to add folate to cereals and other grain products.[2]

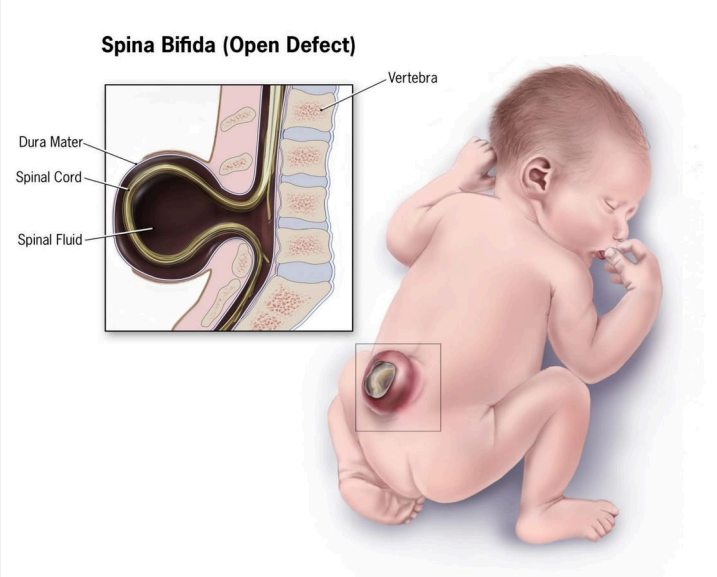


Figure 12.2.1: Image by Centers for Disease Control and Prevention (CDC) / Public Domain

Maternal iron intake during pregnancy is critically important because of the increase in blood volume during pregnancy. Iron is an essential component of hemoglobin, the protein responsible for oxygen transport in blood, so adequate iron intake supports oxygen delivery to both maternal and fetal tissues (see Chapter 10). Babies rely entirely on the iron they store during pregnancy to get them through the first six months of life, because breastmilk is naturally low in iron — making strategies like delayed cord clamping important to help boost the baby's reserves. For mothers, iron is just as critical: going into labor with low iron increases the risk of serious complications or even death during childbirth, especially if there is heavy bleeding, which is common. Good dietary sources of iron include meat, poultry, seafood, nuts, legumes, and fortified or whole grain cereals. At least 27 mg of iron should also be included in a daily prenatal supplement or taken separately.

Iodine is essential for fetal brain development, and recent data suggests that many pregnant women in the U.S. do not consume enough iodine to meet their increased requirement. [15] Much of the iodine in the typical American diet comes from dairy products and iodized salt. However, iodine intake in the U.S. has declined in recent decades as more people watch their intake of table

salt and/or switch to kosher or sea salt, which aren't iodized. In addition, processed foods are generally made with non-iodized salt, and the intake of processed foods has increased. Meanwhile, the popularity of dairy products has declined. Most people in the U.S. still consume enough iodine to meet their requirement, but pregnant women may be at risk for iodine deficiency because of their increased need for this mineral. Iodine deficiency during pregnancy can cause miscarriage, stillbirth, and major neurodevelopmental deficits and growth retardation in the fetus. [16] Unfortunately, many prenatal vitamins do not contain iodine, so it's worth checking the label to ensure that iodine is included. [17]

The micronutrients involved with building the skeleton — vitamin D, calcium, phosphorus, and magnesium — are crucial during pregnancy to support fetal bone development. Although the levels are the same as those for nonpregnant women, many women do not typically consume adequate amounts and should make an extra effort to meet those needs.

As always, it's important to read supplement labels carefully, with the aim of choosing a prenatal supplement that contains close to the RDA or AI for micronutrients and avoiding those that exceed the UL, unless under the specific direction of a healthcare provider. In particular, both vitamin A and zinc consumed in excessive amounts can cause birth defects. Beta-carotene is typically used as the vitamin A source in prenatal supplements, because unlike vitamin A, it doesn't cause birth defects (see Unit 8).

Foods and Other Substances to Avoid

It's not just nutrients that can cross the placenta. Other substances such as alcohol, nicotine, cannabinoids (from cannabis), and both prescription and recreational drugs can also pass from mother to fetus. Exposure to these substances can have lasting and detrimental effects on the health of the fetus. For this reason, pregnant women are advised to avoid using alcohol, tobacco, cannabis, and recreational drugs during pregnancy. Medical providers can help pregnant women quit using these substances and advise them on the safety of specific medications needed during pregnancy. [1]

Some substances are so detrimental that a woman should avoid them even if she suspects that she might be pregnant. For example, consumption of alcoholic beverages results in a range of abnormalities that fall under the umbrella of fetal alcohol spectrum disorders. They include learning and attention deficits, heart defects, and abnormal facial features (Figure 11.5) . Alcohol enters the fetus's bloodstream via the umbilical cord and can slow fetal growth, damage the brain, or even result in miscarriage. The effects of alcohol are most severe in the first trimester, when the organs are developing. There is no known safe amount of alcohol in pregnancy.

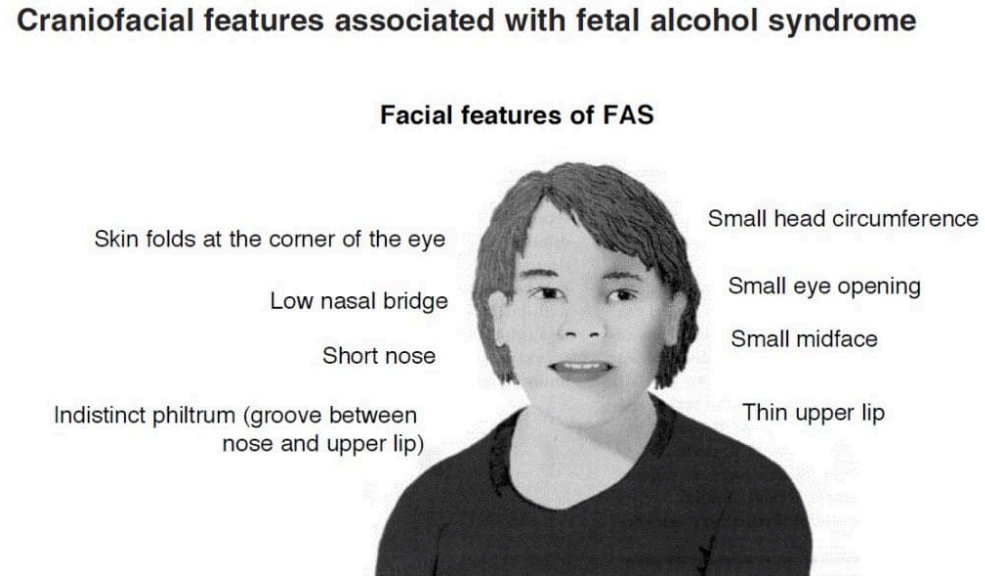


Figure 11.5. Craniofacial features associated with fetal alcohol syndrome.

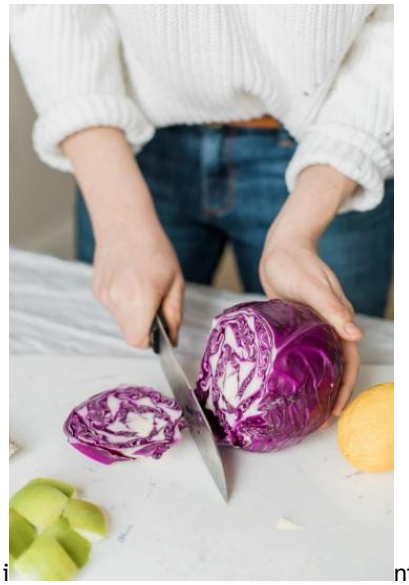
Caffeine use should be limited to less than 200 milligrams per day, or the equivalent of about two cups of coffee. Consumption of greater amounts is linked to miscarriage and preterm birth. Keep in mind that caffeine is also found in other sources such as chocolate, energy drinks, soda, tea, and some over-the-counter pain and headache medications. [1]

It's also important to pay special attention to avoiding foodborne illness during pregnancy, as it can cause major health problems for both the mother and the developing fetus. For example, the foodborne illness caused by the bacteria Listeria monocytogenes , called listeriosis, can cause miscarriage, stillbirth, and fetal or newborn meningitis. According to the CDC, pregnant women are ten times more likely to become ill with this disease than nonpregnant adults, likely because they have a dampened immune response. [19] Other common foodborne illnesses, such as those caused by Salmonella and E. coli , can also be very serious in pregnant women.

Foods more likely to be contaminated with foodborne pathogens should be avoided by pregnant women to decrease their chances of infection. These include the following: [20]

- Unpasteurized dairy products such as soft cheeses
- Raw or smoked seafood
- Hot dogs and deli meats (or heat to 165° before eating)
- Paté and other meat spreads
- Undercooked or raw meat, poultry, and eggs
- Raw sprouts
- Raw dough
- Unpasteurized juice and cider

Following standard food safety practices can also go a long way towards preventing foodborne illness, during pregnancy or anytime. The CDC offers this summary of food safety tips :



- **COOK**. Use a food thermometer to ensure that foods are cooked to a safe internal temperature: 145°F for whole beef, pork, lamb, and veal (allowing the meat to rest for 3 minutes before carving or consuming), 160°F for ground meats, and 165°F for all poultry, including ground chicken and turkey.
- **CLEAN**. Wash your hands after touching raw meat, poultry, and seafood. Also wash your work surfaces, cutting boards, utensils, and grill before and after cooking.
- **CHILL**. Keep your refrigerator below 40°F and refrigerate foods within 2 hours of cooking (1 hour during the summer heat).
- **SEPARATE**. Germs from raw meat, poultry, seafood, and eggs can spread to produce and ready-to-eat foods unless you keep them separate. Use different cutting boards to prepare raw meats and any food that will be eaten without cooking.

Maternal Health During Pregnancy

Discomforts

Especially during the first trimester, it's very common for women to feel nauseous, often leading to vomiting, and to be very sensitive to smells. This so-called "morning sickness" is misnamed, because it can make women feel awful any time of day—morning, noon, and night. Nausea and vomiting during pregnancy affects as many as four out of five pregnancies. Symptoms can range from mild nausea to a much more severe illness called ***hyperemesis gravidarum*** , which causes relentless vomiting

and affects between 0.3 and 3 percent of all pregnancies. Most women find that their nausea and vomiting subsides by the end of the first trimester, but in rare and unfortunate cases, it can continue until the baby is born. [21]

Dietary changes can help alleviate nausea and vomiting. Here are some suggestions: [22]

- **Choose foods that are low in fat and easily digestible**, such as those in the BRATT diet (bananas, rice, applesauce, toast, and tea). The goal is simply to find foods that can be tolerated. It is reassuring to remember that pregnancy does not require extra calories during the first trimester, and a prenatal supplement can help meet micronutrient needs.
- **An empty stomach can worsen feelings of nausea** , so try eating a few crackers or dry toast before getting out of bed in the morning to avoid moving around with an empty stomach. It may also help to eat five or six small meals per day and to eat small snacks such as crackers, fruits, and nuts throughout the day.
- Many pregnant women experiencing nausea and vomiting find meat unappetizing. **Try other sources of protein** such as dairy foods (e.g., milk, yogurt, ice cream), nuts and seeds (as well as nut butters), and protein powders and shakes.
- **Ginger can help settle your stomach ;** it's available in capsule, candy, and tea form. Ginger ale, if made with real ginger, might also be helpful.

If nausea and vomiting remain unmanageable after making these dietary changes, medications may be necessary. Hyperemesis gravidarum, though rare, can be very serious. Constant vomiting can lead to malnutrition, weight loss, dehydration, and electrolyte imbalance. Hospitalization may be required so that women can receive fluids and electrolytes through an intravenous line, and sometimes a feeding tube is necessary. Getting help for this condition can be a frustrating process of trial-and-error, and unfortunately, there are still many unknowns about its causes and effective treatment options. [23]

As pregnancy progresses, another common complaint is **heartburn** , caused by **gastroesophageal reflux .** This is caused by the upward, constrictive pressure of the growing uterus on the stomach, as well as decreased peristalsis in the GI tract. (See Unit 3 for management strategies.)

Complications during Pregnancy

Pregnant people may face different complications during the course of their pregnancy. They include certain medical conditions that could greatly impact a pregnancy if left untreated, such as gestational hypertension and gestational diabetes, which have diet and nutrition implications.

Excessive weight gain

Excessive weight gain during pregnancy is associated with increased risks for both the mother and the developing fetus. For the mother, it raises the likelihood of gestational diabetes, hypertensive disorders such as pre-eclampsia, cesarean delivery, and postpartum weight retention. For the fetus, excessive maternal weight gain is linked to macrosomia (large-for-gestational-age infants), which increases the risk of birth complications, including birth injuries, as well as a higher risk of childhood obesity and metabolic disorders later in life.

Additionally, women who gain more weight than needed for a pregnancy typically retain that excess weight as body fat. If those few pounds increase a new mother's BMI by a unit or more, that could lead to complications such as hypertension or Type 2 diabetes in future pregnancies or later in life.

Even though excessive weight gain during pregnancy can pose health risks for both mother and baby, it's important to note that weight loss during pregnancy is not recommended — instead, the focus should be on slowing the rate of weight gain to stay within healthy guidelines.

Gestational hypertension

Gestational hypertension is a condition of high blood pressure during the second half of pregnancy.

First-time mothers are at a greater risk, along with women who have mothers or sisters who had gestational hypertension, women carrying multiple fetuses, women with a prior history of high blood pressure or kidney disease, and women who are overweight or who have obesity when they become pregnant. Hypertension can prevent the placenta from getting enough blood, which would result in the baby getting less oxygen and nutrients. This can result in low birth weight, although most women with gestational

hypertension can still deliver a healthy baby if the condition is detected and treated early.

Some risk factors can be controlled, such as diet and efforts to address excessive weight gain, while others cannot, such as family history. If left untreated, gestational hypertension can lead to a serious complication called **preeclampsia** and **eclampsia**, which can be fatal. This disorder is marked by elevated blood pressure and protein in the urine and is associated with swelling. The World Health Organization (WHO) recommends specific nutritional interventions to reduce the risk of pre-eclampsia, particularly in low-resource or high-risk populations: (WHO Recommendations for Prevention and Treatment of Pre-eclampsia and Eclampsia (2011)).

- Calcium Supplementation: Daily supplementation with 1.5–2.0 g of elemental calcium is recommended for pregnant women with low dietary calcium intake (<1000 mg/day). It significantly reduces the risk of pre-eclampsia, especially when initiated before 20 weeks of gestation.
- Balanced Energy and Protein Intake: For undernourished women, balanced energy-protein supplementation is advised to improve maternal outcomes and reduce the risk of pre-eclampsia and other complications.
- Magnesium: Routine magnesium supplementation is not recommended for prevention due to insufficient evidence. However, magnesium sulfate is the treatment of choice for women with severe pre-eclampsia or eclampsia.
- Salt Intake: Restricting dietary salt below normal levels during pregnancy is not advised, as it does not prevent hypertensive disorders.

Gestational diabetes

About 6 percent of pregnancies in the U.S. are affected by **gestational diabetes** (see Unit 4). [24] This is a type of diabetes that develops during pregnancy in women who didn't previously have diabetes. Gestational diabetes is managed by monitoring blood glucose levels, eating a healthy diet, and exercising regularly. Sometimes, insulin injections are needed. If blood glucose levels aren't well controlled in the mother, the fetus will also have high blood glucose levels. This can cause the baby to grow too big (macrosomia), leading to a greater chance of birth complications and increased likelihood of needing a cesarean birth. [25]

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12.3: Nutrition for Lactation in Early Infancy



Infancy is a time of dramatic change and development. In the first year of life, babies triple their body weight and develop from tiny bundles whose daily activities involve eating, sleeping, and creating dirty diapers to toddlers well on their way to walking, talking, and feeding themselves. The first 1,000 days of life, beginning at conception and continuing through toddlerhood, also represent the most active period of brain development in the lifespan, laying the foundation and establishing neural networks to support cognitive, motor, and social-emotional skills throughout life. All of these critical developmental processes are supported through sensitive caregiving, a safe home environment, and of course, a healthy diet.[1] Nutrient requirements on a per-kilogram body weight basis are higher during infancy than in any other stage in the lifespan.

Early Infancy: Meeting Nutrient Needs Through Milk

At birth and continuing through the first 6 months of life, breast milk, infant formula, or some combination of the two are the only necessary source of nutrition for young infants. This is because young infants' gastrointestinal tracts aren't yet ready to process more complex foods, and they lack the oral motor skills to swallow solid foods safely. Breast milk is uniquely adapted to meet the nutrient needs of young infants, and infant formula is also designed and regulated to ensure that it is safe and provides adequate nutrition. Any other substitute, including cow's milk, goat's milk, plant-based beverages such as soy milk, homemade infant formula, or watered down formula, should be avoided. These do not provide the right balance of nutrients to meet infants' requirements and can cause serious problems such as damage to the intestines or kidneys.[2]

Choosing breastfeeding or formula-feeding

The World Health Organization and the American Academy of Pediatrics, as well as many other health organizations, recommend that infants be exclusively breastfed (only receiving breast milk, with no formula or other foods) for the first 6 months of life. Breast milk is considered the optimal source of nutrition for infants, but it also contains many other bioactive molecules, including immunoglobulins (or antibodies), hormones, enzymes, growth factors, and protective proteins.[3] In addition, breast milk contains special carbohydrates, called human milk oligosaccharides, that are indigestible to infants (they lack the enzymes to break them down) but help to establish a healthy gut microbiome by serving as a food source for friendly bacteria and binding up harmful bacteria.[4]

Breastfeeding is beneficial to babies in many ways; it reduces a baby's risk of gastrointestinal, respiratory, and ear infections, and it may also protect babies from sudden infant death syndrome (SIDS), eczema, and asthma. It is also associated with a small increase in IQ and a reduced risk of obesity later in childhood. In addition, breastfeeding benefits the health of mothers; it's associated with a reduced risk of hypertension, type 2 diabetes, and breast and ovarian cancer.[3] However, it's important to note that most of the data on benefits of breastfeeding come from observational studies, and these studies have many confounding

factors. Women who breastfeed tend to have higher incomes, be more educated, be older in age, and are more likely to be white compared with those who don't breastfeed. This means breastfed babies are often born with more advantages beyond how they are fed, so it can be difficult to separate correlation from causation in studies of infant feeding outcomes.[5]



Despite the challenges in breastfeeding research, breastfeeding has many well-established benefits, and most mothers intend to breastfeed. In 2017, 84% of babies born in the U.S. were breastfed at birth, but just 58% were still breastfeeding at 6 months of age, and 26% were exclusively breastfed through 6 months.[6] These statistics represent the many challenges women face with breastfeeding. Although breastfeeding is natural, it doesn't always come naturally or easily. Breastfeeding challenges can often be addressed with the help of an experienced professional such as a lactation consultant, but this support is not easy for all women to access. Women may also find it hard to establish and continue breastfeeding if they have to return to work just a few weeks or months postpartum, a scenario common in the U.S., the only high-income country in the world that still has no national policy for paid parental leave.[7,8]

Some cities, such as San Francisco, have adopted policies to address some of these barriers. In 2017, San Francisco enacted a landmark policy to promote and protect breastfeeding in the workplace, spearheaded by then-Supervisor Katy Tang. Recognizing the numerous barriers lactating parents face — such as the lack of private, sanitary spaces to pump breast milk (often relegated to restrooms), absence of cold storage, limited break times, and social stigma stemming from the sexualization of breasts — the "Lactation in the Workplace" ordinance set a new national standard. The policy requires all employers in San Francisco to provide a clean, private, non-bathroom space for lactation, access to a nearby sink and refrigerator, and reasonable break time to express milk. Tang's initiative acknowledged breastfeeding not only as a personal choice but as a public health issue, emphasizing equity for working parents. This ordinance aimed to dismantle structural barriers that disproportionately affect low-wage workers and normalize breastfeeding in both private and public life.

Key Features of the San Francisco Lactation Policy:

- Requires employers to provide a **private, non-bathroom space** for lactation that is clean and safe.
- Mandates **access to a refrigerator and sink** close to the lactation space.
- Guarantees **reasonable break time** specifically for pumping breast milk.
- Applies to **all new building permits** for workplaces to include lactation space in design plans.
- Establishes a **clear written policy** that must be shared with all employees.
- Addresses **inequities** and helps reduce stigma by framing lactation as a workplace right, not a privilege.

There are also a few circumstances in which babies should not or can not be breastfed. In the U.S., it's recommended that women

infected with HIV do not breastfeed, because the virus can pass to infants in milk. Infants born with rare metabolic disorders may not be able to metabolize breast milk and need to receive special formulas. There are also some medications which, if taken by the mother, are not safe for breastfeeding infants. In these cases, mothers may be advised to formula-feed.[3]

Many women find breastfeeding enjoyable and a wonderful way to bond with their baby. For others, breastfeeding can be a struggle for one or more of the reasons discussed above, and that struggle can overshadow a mother's relationship with her baby. For all of these reasons, the choice to breastfeed or formula-feed, or to feed some of both, is complex and individual. Parents should be supported whatever their decision, and they can be confident that infant formula is a safe, nutritionally-adequate option.

What Can We All Do to Support Those Who Wish to Breastfeed?

Supporting breastfeeding goes beyond individual choices of the parent — it's about creating a culture that respects and uplifts those who want to feed their children in this nutritionally ideal, biologically intended way. First, we can advocate for policies that protect breastfeeding rights, including those that ensure access to lactation spaces at work and in public places. Every Mother's Day is a reminder and an opportunity to advocate for what truly supports motherhood — including paid maternal leave, access to lactation support, and protected time and space at work for breastfeeding.

Just as importantly, we can shift everyday behaviors: that means not staring, shaming, or harassing people who breastfeed in public. After all, breastfeeding is one of the most biologically human things we can do — we are mammals, after all! The World Health Organization's Baby Friendly Hospital Initiative highlights the role of both healthcare providers and family members in supporting breastfeeding from the very beginning. This includes steps like immediate skin-to-skin contact after birth and educating families about how to support exclusive breastfeeding.



Social attitudes begin forming early — when toy baby dolls include bottles, or when emojis default to a bottle after typing "baby," we're already reinforcing a bottle-feeding norm. Choosing toys and media that de-emphasize bottle-feeding normalize breastfeeding, and teaching children that feeding babies can happen in different ways, can help reshape these perceptions.

Members of a community can also promote and support breastfeeding. New mothers can join peer counseling groups or turn to other women within their community who have previous experience with breastfeeding. In addition, community-based programs can provide education and support. The US Department of Agriculture's Women, Infants, and Children program provides information on breastfeeding and both professional and peer support for women and their babies from low-income families. Launched in 2004, the Loving Support program combines peer counseling with breastfeeding promotion efforts to increase duration rates across the United States. La Leche League is an international program that provides mother-to-mother support, encouragement, and education about breastfeeding for women around the world. For more information on La Leche League, visit https://www.llli.org.

Although breastfeeding should be recommended and encouraged for almost all new mothers, it is important to remember that the decision to breastfeed is a personal choice and women should not be made to feel guilty if they cannot, or choose not,

to breastfeed their infants. When someone chooses to bottle-feed, it's essential to withhold judgment. The bottle may contain expressed breastmilk, or there may be compelling medical, emotional, or personal reasons why someone isn't breastfeeding — such as a parent who has undergone breast removal surgery, or families with two dads. In some rare cases, a woman is unable to breastfeed or it is not in the baby's best interest, for example if the baby has galactosemia, an inborn error of metabolism. Compassion and support — not judgment — should guide how we respond to all infant feeding choices.

Nutritional choices that parents make, such as the decision to breastfeed or bottle-feed, not only affect early childhood development, but also a child's health and wellness later in life. Therefore, it is imperative to promote and support the best practices for the well-being of infants and mothers alike.

Nutrient Composition of Breast Milk

The first milk, called ***colostrum***, is produced immediately after birth and continues for the first two to five days after the arrival of the baby. Colostrum is yellowish in color, thicker than mature breast milk, and produced in small quantities. It is low in fat and easily digestible, yet rich in protein, fat-soluble vitamins, and minerals. Colostrum is also a concentrated source of immunoglobulins that pass from the mother to the baby and provide immune protection to the newborn. The stomach capacity of newborns is small, so they only consume a teaspoon or two of colostrum per feeding in the first few days of life, but they need to feed often. Frequent, on-demand feeding (whenever the baby is hungry, not on a schedule) helps to promote full milk production.[5]

After a couple of days, colostrum is replaced by transitional milk, which is produced in much greater volume and lasts through 7 to 14 days postpartum. Compared with colostrum, transitional milk has more fat and lactose, and less protein and immunoglobulins, and it is also more calorie-dense. Finally, women begin to produce mature milk and will continue to make this type of milk through the end of lactation. Mature milk contains about 87% water, 4% fat, 1% protein, and 7% lactose. Together, these meet infants' macronutrient and caloric requirements.[9]



However, there is variability even within mature milk. In a given feeding, the milk secreted at the beginning of the feeding (called foremilk) is thinner and higher in lactose than the milk at the end of the feeding (called hindmilk). The higher levels of fat in the hindmilk helps to ensure the baby's energy needs are met.[9] Milk can also vary from day to night; nighttime milk is higher in fat and the sleep-promoting hormone melatonin.[10] As breastfeeding continues beyond 6 or 7 months, the levels of some vitamins and minerals begin to decline. This is around the time that babies begin to eat some solid foods, so foods can help to fill in nutritional gaps, while breast milk continues to be an important source of nutrients.[5]

Breast milk provides enough of all of the micronutrients that young infants need with two main exceptions: vitamin K and vitamin D. For this reason, newborns should receive a vitamin K shot soon after birth; otherwise, vitamin K deficiency can lead to serious bleeding disorders such as hemorrhage (see Chapter 9). The American Academy of Pediatrics also recommends that breastfed newborns be given a vitamin D supplement beginning in the first few days of life and continuing until they are weaned to formula or cow's milk, both of which are fortified with adequate vitamin D. (Cow's milk can be given beginning at 12 months of age.)[11]

Breast milk is also low in iron, although what little is there is absorbed very efficiently. Newborns are born with a certain amount of

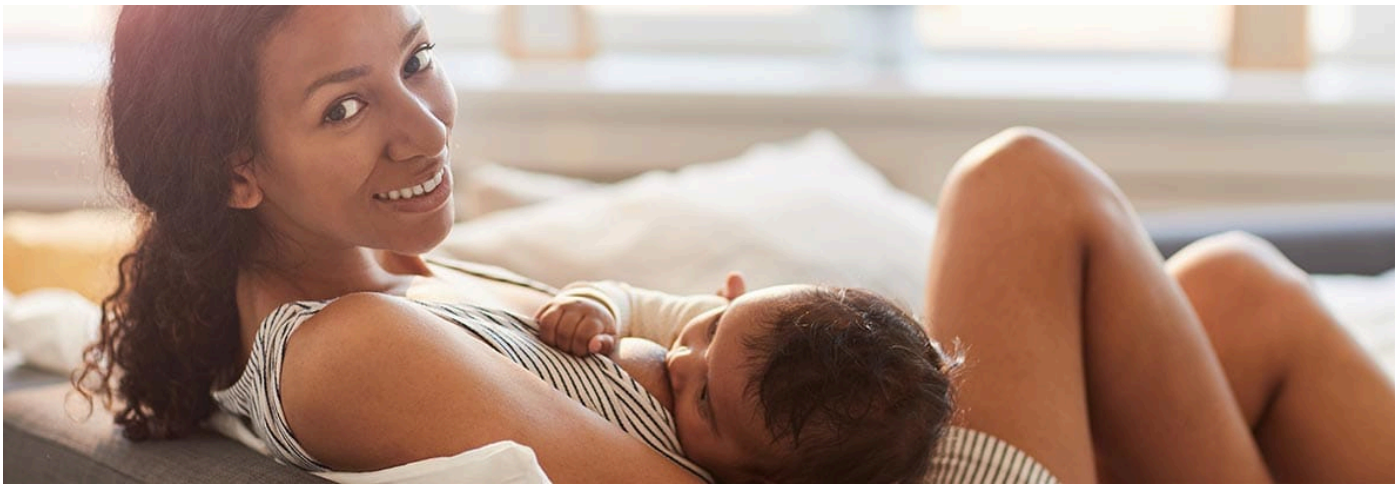
iron absorbed from their mothers during pregnancy, and they utilize this stored iron — in addition to that provided in breast milk — to meet their iron requirement in early infancy. However, stored iron is depleted by around 4 months of age, so the American Academy of Pediatrics recommends that exclusively breastfed infants begin taking an iron supplement at this age and continuing until they are eating substantial amounts of iron-rich solid foods, such as meat or iron-fortified cereals. Iron deficiency remains a significant problem, with 11% of 1-year-olds in the U.S. estimated to be iron-deficient.[11] Iron is essential for brain development, and iron deficiency may cause lasting developmental deficits.[12]

Nutrition for Breastfeeding Mothers

Breastfeeding mothers have nutrient requirements similar to women in the third trimester of pregnancy. After all, they're continuing to provide nutrients for their babies through their milk, and milk production requires energy, macronutrients, micronutrients, and water. Breastfeeding women have a remarkable ability to make enough milk to meet their babies' nutrient needs even without an optimal diet, but eating well supports maternal health and energy levels during this demanding time.

Breastfeeding increases energy requirements by about 450 to 500 calories per day, part of which can be supplied by using adipose stored in pregnancy and part of which should be supplied from greater caloric intake. In general, breastfeeding mothers can eat a wide variety of foods, and they don't usually need to avoid or restrict any specific foods. However, as in pregnancy, they should continue to avoid high-mercury fish. Consuming low-mercury fish 2 to 3 times per week provides the omega-3 fatty acids DHA and EPA, which pass into breast milk and support brain and eye development for the breastfeeding infant.[13] There is no need to avoid common food allergens, such as peanut or dairy; avoiding these foods while breastfeeding has not been shown to reduce babies' chances of developing food allergies.[14] Sometimes women find that certain foods, such as garlic or spicy foods, are associated with fussiness or gas in their infants, and they may experiment with avoiding those foods. However, most infants don't have a problem tolerating these foods. In fact, flavors from the mother's diet pass into breast milk, so researchers hypothesize that when mothers eat a wide variety of foods and flavors while breastfeeding, their children grow up to be more adventurous eaters.[15]

In addition to consuming a nutrient-dense diet, obstetricians sometimes recommend that breastfeeding mothers continue taking a prenatal supplement to ensure that their micronutrient needs are met. Breastfeeding mothers should also be sure to drink plenty of fluids to support milk production.[13]



Similar to pregnancy, substances consumed by the breastfeeding mother can pass to the infant in her milk. However, how much passes into the milk depends on the type of substance and the timing of consumption relative to breastfeeding. For example, it's considered safe for a breastfeeding mother to have an alcoholic drink so long as she waits at least two hours before breastfeeding, because by that point, most of the alcohol will have cleared her bloodstream and will not pass into her milk. Caffeine lasts longer in the blood but is considered safe in moderation, with a limit of about 300 milligrams per day.[13] Cannabinoids, the chemicals found in cannabis, are fat-soluble and remain in a mother's bloodstream and body tissues for much longer. Tetrahydrocannabinol (THC), the main psychoactive chemical in cannabis, has been detected in breast milk as much as 6 weeks after a mother used cannabis.[16] Although it's not clear how these chemicals affect babies when consumed in breast milk, medical organizations agree it's best to avoid using cannabis while breastfeeding.

The National Institutes of Health's LactMed database is a great resource for information about the safety of drugs, medications, and supplements during breastfeeding.

Nutrient Composition of Infant Formula

To a certain extent, the nutrient composition of infant formula is modeled after that of human milk, and although it by no means duplicates breast milk, it is a safe and effective substitute. Formula is made from ingredients such as cow's milk, soy, vegetable oils, and corn syrup. These may be combined in ways to mimic the overall macronutrient composition of breast milk, but the content of individual amino acids, fatty acids, and sugars can vary somewhat. In addition, some of these nutrients are less digestible, so to compensate, formulas tend to have higher levels of some nutrients, such as protein, compared with breast milk. Formula contains more of some micronutrients, such as iron, vitamin D, and vitamin K, so deficiencies of these vitamins and minerals are more common in breastfed infants if they don't receive appropriate supplementation or solid foods when the time comes.[17]

Infant formula also does not contain most of the bioactive molecules found in breast milk, although formula companies are beginning to add versions of some of these molecules. For example, many formulas now include some type of indigestible sugar molecule intended to act as a prebiotic to feed healthy gut bacteria, similar to human milk oligosaccharides. At this point, however, the evidence that such ingredients are beneficial to infants is not very convincing. However, novel ingredients like these are often used as marketing tools, with labels touting vague structure-function claims such as "brain-boosting" and "immune-supporting." Consumers should know that there is often little evidence that "designer ingredients" in infant formula make them healthier for babies. All infant formulas are required by law to be safe and meet the nutrient requirements of infants, and in most cases, basic store brand formulas cost less and are just as good as other products on the shelf. It may be true that infant formula can't replicate the complexity of breast milk, but it has a very strong track record of safety, and infants can grow and thrive with formula-feeding.[17]



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12.4: More on nutrition in the first 6 months of life

Diet and nutrition have a major impact on a child's development from infancy into the adolescent years. A healthy diet not only affects growth, but also immunity, intellectual capabilities, and emotional well-being. One of the most important jobs of parenting is making sure that children receive an adequate amount of needed nutrients to provide a strong foundation for the rest of their lives.



Figure 12.4.1: Image by Marie Kainoa Fialkowski Revilla / CC BY 4.0

Most expectant mothers begin thinking about how they will feed their baby early in their pregnancy. Therefore, it is important to offer breastfeeding education and support starting with the first prenatal appointment. Support from family members, especially the baby's father and grandmother, plus friends, employers, and others can greatly help with both the decision-making process during pregnancy and the beginning and maintenance of breastfeeding after the baby's birth. In the United States, about 83.2 percent of babies start out being breastfed.[1] Yet by the age of six months, when solid foods should begin to be introduced into a child's diet along with breast milk, only about 25 percent of infants in the United States were still breastfed exclusively, according to the Centers for Disease Control and Prevention (CDC).[2]

The approval and assistance of family members, friends, employers, health-care providers, and policymakers can make an enormous difference and provide the needed promotion and support for mothers who wish to breastfeed their children. Education about breastfeeding typically begins with health-care providers. During prenatal care and often soon after a woman has given birth, doctors, nurses, and other clinicians can explain the benefits of breastfeeding and describe the proper technique. Nearly all births in the United States and Canada occur in hospital settings, and hospital practices in labor, delivery, postpartum care, and discharge planning can inform and support women who want to breastfeed. Once a new mother has left the hospital for home, she needs access to a trained individual who can provide consistent information. International Board Certified Lactation Consultants (IBCLCs) are health-care professionals (often a registered nurse or registered dietitian) certified in breastfeeding management that work with new mothers to solve problems and educate families about the benefits of this practice. Research shows that breastfeeding rates are higher among women who had infants in hospitals that make IBCLCs available to new mothers, rather than those who gave birth in institutions without these professionals on staff.[3]

Other important practices for maternity hospitals to support breastfeeding are summarized in the Ten Steps to Successful Breastfeeding — mentioned in the previous section — launched jointly by the WHO and UNICEF.[4] These recommended practices include: helping mothers initiate breastfeeding within one hour of birth; keeping mothers and babies together (rooming in); encouraging breastfeeding on demand, and giving breastfed infants no food or drink other than breastmilk, unless medically indicated.

In addition, spouses, partners, and other family members can play critical roles in helping a pregnant woman make the decision

to breastfeed and assisting with feeding after the baby is born. Employment can also factor into a woman's decision to breastfeed or her ability to maintain the practice. Employed mothers have been less likely to initiate breastfeeding and tend to breastfeed for a shorter period of time than new mothers who are not employed or who have lengthy maternity leaves. In 2010 in the United States, the passage of the Affordable Care Act (ACA) required most employers to provide accommodations within the workplace for new mothers to pump breast milk. This law requires a private and clean space within the workplace, other than a restroom, along with adequate break time for a woman to express milk.[5]It also requires health insurance to cover certain breastfeeding services and supplies such as a breast pump.

Additionally, some states have passed several bills to support breastfeeding. These bills provide a number of rights to breastfeeding women such as: the right to breastfeed in public, the right to pump breastmilk at work (extending beyond the ACA worksite protections), protection from an employer from firing or penalizing a lactating employee because the employee breastfeeds or expresses milk at the workplace,[6] and the right for breastfeeding mothers to decline jury duty until the child is 1 year old.[7] See: https://wicworks.fns.usda.gov/resources/50-state-summary-breastfeeding-laws

Members of a community can also promote and support breastfeeding. New mothers can join peer counseling groups or turn to other women within their community who have previous experience with breastfeeding. In addition, community-based programs can provide education and support. The US Department of Agriculture's Women, Infants, and Children program provides information on breastfeeding and both professional and peer support for women and their babies from low-income families. Launched in 2004, the Loving Support program combines peer counseling with breastfeeding promotion efforts to increase duration rates across the United States. La Leche League is an international program that provides mother-to-mother support, encouragement, and education about breastfeeding for women around the world. For more information on La Leche League, visit https://www.llli.org.

Infancy (Birth to Age One)

A number of major physiological changes occur during infancy. The trunk of the body grows faster than the arms and legs, while the head becomes less prominent in comparison to the limbs. Organs and organ systems grow at a rapid rate. Also during this period, countless synapse pathways to link brain neurons are reinforced while others are trimmed back in the brain. Two soft spots on the baby's skull, known as fontanels, allow the skull to accommodate rapid brain growth. The posterior fontanel closes first, by the age of eight weeks. The anterior fontanel closes about a year later, at eighteen months on average. Developmental milestones include sitting up without support, learning to walk, teething, and vocalizing among many, many others. All of these changes require adequate nutrition to ensure development at the appropriate rate.[8]



Figure 12.4.2: Image by Marie Kainoa Fialkowski Revilla / CC BY 4.0

Healthy infants grow steadily, but not always at an even pace. For example, during the first year of life, height increases by 50 percent, while weight triples. Physicians and other health professionals use growth charts to track a baby's development process. Because infants cannot stand, length is used instead of height to determine the rate of a child's growth. Other important

developmental measurements include head circumference and weight. All of these must be tracked and compared against standard measurements for an infant's age.

In the US, for infants and toddlers from birth to 24 months of age, the WHO growth charts are used to monitor growth. These standards represent optimal growth for children at this age and allow for tracking growth trends over time through percentile rankings. Growth charts may provide warnings that a child has a medical problem or is malnourished. Growth that is too rapid can increase the risk for overweight and obesity in childhood and later in life. 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.

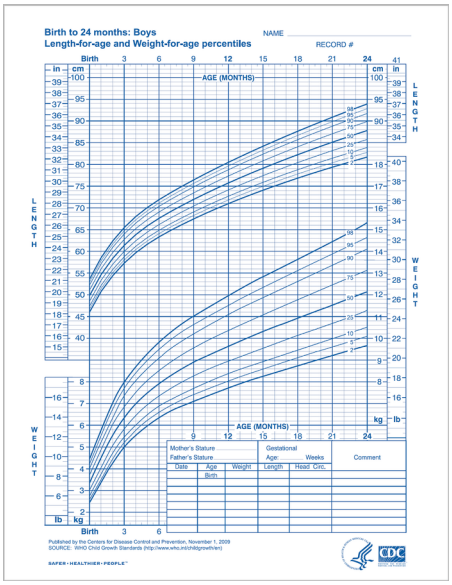


Figure 12.4.3: WHO Growth Chart For Boys From Birth To 24 Months. Image by Centers for Disease Control and Prevention / Public Domain

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 synthesis of DNA and other cellular components. During this period, children are entirely dependent on their parents or other caregivers to meet these needs. For almost all infants six months or younger, breast milk is the best source to fulfill nutritional requirements. An exclusively breastfed infant does not even need extra water, including in hot climates.

A newborn infant (birth to 28 days) requires feedings eight to twelve times a day or more. Between 1 and 3 months of age, the breastfed infant becomes more efficient, and the number of feedings per day often become fewer even though the amount of milk consumed stays the same. After about six months, infants can gradually begin to consume solid foods to help meet nutrient needs. Foods that are added in addition to breastmilk are called complementary foods. Complementary foods should be nutrient dense to provide optimal nutrition. Complementary foods include baby meats, vegetables, fruits, infant cereal, and dairy products such as yogurt, but not infant formula. Infant formula is a substitute, not a complement to breastmilk. In addition to complementary foods, the World Health Organization recommends that breastfeeding continue up to 2 years of age or beyond, and the American Academy of Pediatrics recommends at least one year of breastfeeding, or longer. [9]

Energy and Macronutrients

Energy needs relative to size are much greater in an infant than an adult. A baby's resting metabolic rate is two times that of an adult. The RDA to meet energy needs changes as an infant matures and puts on more weight. The IOM uses a set of equations to calculate the total energy expenditure and resulting energy needs. For example, the equation for the first three months of life is (89 x weight [kg] –100) + 175 kcal.

Based on these equations, the estimated energy requirement for infants from zero to six months of age is 472 to 645 kilocalories per day for boys and 438 to 593 kilocalories per day for girls. For infants ages six to twelve months, the estimated requirement is 645 to 844 kilocalories per day for boys and 593 to 768 kilocalories per day for girls. From the age one to age two, the estimated requirement rises to 844–1,050 kilocalories per day for boys and 768–997 kilocalories per day for girls.[10] 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.

The dietary recommendations for infants are based on the nutritional content of human breast milk. Carbohydrates make up about 40 to 55percent of the caloric content in breast milk, which amounts to a RDA (AI) of about 60 grams for infants 0-6 months old, and 95 grams for infants 7-12 months old. Almost all of the carbohydrate in human milk is lactose, which infants digest and tolerate well. In fact, lactose intolerance is practically nonexistent in infants. Protein makes up about 5 to 9 percent of the caloric content of breast milk, which amounts to a RDA (AI) of 9.1 grams per day for infants 0-6 months, and a RDA of 11 grams per day for infants 7-12 months. Infants have a high need for protein to support growth and development, although excess protein (which is only a concern with bottle-feeding) can cause dehydration, diarrhea, fever, and acidosis in premature infants. About 30 to 50 percent of the caloric content in breast milk is made up of fat. A high-fat diet that includes cholesterol is necessary to support the development of neural pathways in the brain and throughout the body. However, saturated fats and trans fatty acids inhibit this growth. Infants who are over the age of six months, which means they are receiving complementary foods, should not consume foods that are high in these types of fats. The RDA (AI) for total fat is 30 grams per day for infants 0-6 months old and 31 grams per day for infants 7-12 months old.

Micronutrients

Almost all of the nutrients that infants require during the first 6 months can be met if they consume an adequate amount of breast milk. There are a few exceptions, though. Unless the mother is taking a large dose of Vitamin D, human milk will be low in vitamin D, which is needed for calcium absorption and building bone, among other things. Therefore, breastfed children often need to take a vitamin D supplement in the form of drops. Infants at the highest risk for vitamin D deficiency are those with darker skin and little to no exposure to sunlight, and infants born prematurely. Breast milk is also low in vitamin K[11], which is required for blood clotting, and deficits could lead to bleeding or hemorrhagic disease. Babies are born with limited vitamin K, so supplementation may be needed initially and some states require a vitamin K injection after birth. Also, breast milk is not high in iron, but the iron in breast milk is well absorbed by infants. After five to eight months, however, an infant needs an additional source of iron other than breast milk. For exclusively breastfed infants, 6 months of age is a good time to introduce sources of highly bioavailable iron and zinc such as baby meats. Iron-fortified cereals and beans can boost the iron intake as well.

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 higher metabolic rate. Therefore, they are at greater risk of dehydration. However, parents or other caregivers can meet an infant's fluid needs with breast milk or formula. As solids are introduced, parents must make sure that young children continue to drink fluids throughout the day.

Breastfeeding

Although few aspects of human nutrition are surrounded by as much public controversy as is the choice to breastfeed or formula feed an infant, a little knowledge about the science of breastfeeding can go a long way to settling this debate. This section will cover the science of lactation and practical ways to improve both the breastfeeding experience and the nutritional status of mothers and infants. Learning about the different parts of the breast and their function is a first step to becoming better able to support mothers who want to breastfeed.

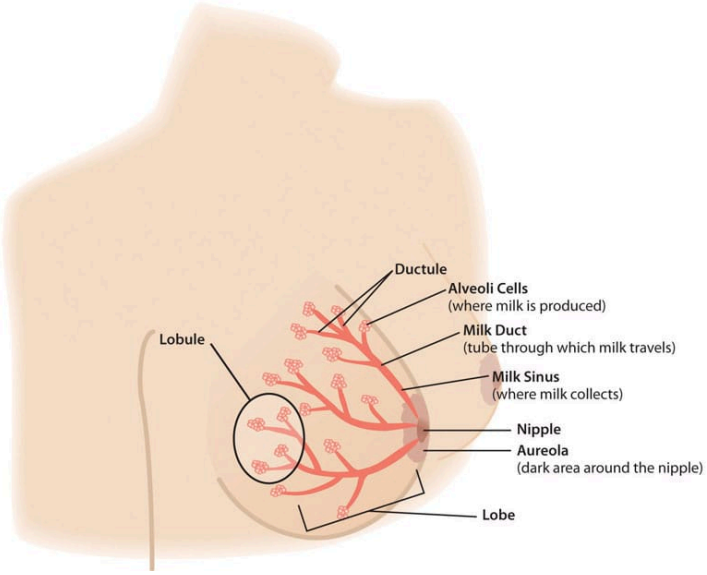


Figure 12.4.4: Copy and Paste Caption here. (Copyright; author via source)

The structure of the breast includes the alveoli which are grape-like clusters where milk is made. A network of ducts branch out and carry the milk from the alveoli to the nipple. A tiny muscle surrounds each of the alveoli; when a baby nurses at the breast, a hormone is released from the mother's brain that makes these muscles contract and push the milk out into the ducts and towards the nipple. Groups of alveoli connected by ducts are organized into lobes, or sections, of the breast. The breast contains 15 to 25 lobes, and each lobe contains 10 to 100 alveoli.

The areola is the darker skin around the nipple and is a visual target that helps the baby find the breast. The bumps on the areola are glands that provide lubrication and protection to the tissue. These glands also produce a scent to help the baby find the nipple. The nipple and areola contain erectile smooth muscles that contract to make the nipple protrude more during breastfeeding. Nipples come in many sizes and shapes and contain from 4 to 18 openings for the milk to flow out. Mothers do not need to do anything to get their nipples ready to breastfeed.

Breast size is mainly determined by the amount of fat in the breast; the milk-making structures don't vary as much as the amount of fat tissue. Most mothers can make enough milk for their babies whether they have small or large breasts. It is normal for a woman to have one breast that is different than the other in size or shape. During pregnancy, the breasts will normally increase in size. If a woman does not notice any changes to her breast during pregnancy, she should discuss this with her healthcare provider or a lactation consultant.

After the birth of the baby, nutritional needs must be met to ensure that an infant not only survives, but thrives from infancy into childhood. Breastfeeding provides the fuel a newborn needs for rapid growth and development. As a result, the WHO recommends that breastfeeding is exclusive (no other food or drink) for the first six months of an infant's life. Exclusive breastfeeding is one of the best ways a mother can support the growth and protect the health of her infant child. Breast milk contains nearly all of the nutrients that a newborn requires and gives a child the best start to a healthy life. Most women want to breastfeed their babies; in the US, over 80% of women start to breastfeed their infants. Unfortunately, a mother's intention alone may not be enough to make this practice successful. Around the world, approximately 40 percent of infants are breastfed exclusively for the recommended 6 months.[12][13][14]

New mothers must also pay careful consideration to their own nutritional requirements to help their bodies recover in the wake of the pregnancy. This is particularly true for women who breastfeed their babies, which increases the need in certain nutrients.

Lactation

Preparation for making breast milk, although begun in puberty, is not completed until a woman's first pregnancy. Early in the first trimester, the cells that will secrete milk divide and multiply. Hormones play a major role in preparing the woman's body to breastfeed, 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. Also during pregnancy, progesterone stimulates growth of the alveoli, the clusters of cells where the milk is made. During this process ducts that will carry the milk grow larger

and branch out, and new capillaries are also formed to circulate the increased blood supply. 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.[15] When the infant suckles at the breast, levels of the hormone oxytocin rise to promote the release of breast milk from the breast when the infant suckles, which is known as the milk-ejection reflex.

New mothers usually find that their appetite and thirst is greater than before pregnancy; it is recommended that they still focus on nutrient-dense foods to nourish their body and replace their body's nutrient stores. A conservative rate of weight loss (1-2 pounds per week) during lactation does not usually impact the quantity or quality of breast milk, but maternal deficiencies in some nutrients have been described during lactation. The nutrient content of breastmilk does not change much based upon maternal diet for most nutrients. The RDA for energy is 330 additional Calories during the first six months of lactation and 400 additional Calories during the second six months of lactation. The energy needed to support breastfeeding comes from both increased intake and from stored fat. For example, during the first six months after her baby is born, the daily caloric cost for a lactating mother is 500 Calories, with 330 calories derived from increased intake and 170 Calories derived from maternal fat stores. This helps explain why breastfeeding may promote weight loss in new mothers. Lactating women should also drink 3.1 liters of liquids per day (about 13 cups) to avoid dehydration, according to the IOM. As is the case during pregnancy, the RDA of most vitamins and minerals increases for women who are breastfeeding their babies. Most doctors and nutritionists recommend that lactating women continue taking their prenatal vitamin/mineral supplement during lactation. The following table compares the recommended vitamins and minerals for lactating women to the levels for nonpregnant and pregnant women.

Table 12.4.1*: Recommended Nutrient Intakes during Lactation*

Nutrient	Nonpregnant Women	Pregnant Women	Lactating Women
Vitamin A (mcg)	700.0	770.0	1,300.0
Vitamin B6 (mg)	1.3	1.9	2.0
Vitamin B12 (mcg)	2.4	2.6	2.8
Vitamin C (mg)	75.0	85.0	120.0
Vitamin D (mcg)	5.0	5.0	5.0
Vitamin E (mg)	15.0	15.0	19.0
Calcium (mg)	1,000.0	1,000.0	1,000.0

Nutrient	Nonpregnant Women	Pregnant Women	Lactating Women
Folate (mcg)	400.0	600.0	500.0
Iron (mg)	18.0	27.0	9.0
Magnesium (mg)	310.0	350.0	310.0
Niacin (B3) (mg)	14.0	18.0	17.0
Phosphorus	700.0	700.0	700.0
Riboflavin (B2) (mg)	1.1	1.4	1.6
Thiamine (B1) (mg)	1.1	1.4	1.4
Zinc (mg)	8.0	11.0	12.0

Source: Institute of Medicine (2006). *Dietary reference intakes: The essential guide to nutrient requirements*. The National Academies Press. https://www.nap.edu/catalog/11537/di...t-requirements

Calcium requirements do not change during breastfeeding because of more efficient absorption, which is the case during pregnancy, too. However, the reasons for this differ. During pregnancy, there is enhanced absorption within the gastrointestinal tract. During lactation, there is enhanced retention by the kidneys. The RDA for phosphorus and fluoride also remains the same.

Components of Breastmilk

Human breast milk not only provides adequate nutrition for infants, it also helps to protect newborns from disease. In addition, breast milk is rich in cholesterol, which is needed for brain development. It is helpful to know the different types and components of breastmilk, along with the nutrients they provide to enable an infant to survive and thrive.

Colostrum is the milk produced immediately after birth, prior to the start of mature milk production, and lasts for two to five days after the arrival of the baby. Cells in the breast can begin to secrete colostrum by mid-pregnancy. During the last trimester, the alveoli (grape-like clusters of cells that produce milk) can become swollen with colostrum. Colostrum is thicker than mature breast milk, and is yellowish or creamy in color. This protein-rich liquid fulfills an infant's nutrient needs during those early days. Although low in volume, colostrum is packed with concentrated nutrition for newborns. This special milk is high in fat-soluble vitamins, minerals, and immunoglobulins (antibodies) that pass from the mother to the baby. Immunoglobulins provide passive

immunity for the newborn and protect the baby from bacterial and viral diseases.[16] Colostrum also helps the baby to eliminate waste (meconium).

Two to four days after birth, colostrum is replaced by transitional milk. Nursing the baby early (within the first hour of birth) and frequently (8 to 14 times per 24 hours) helps to bring in this increased volume of milk sooner. Transitional milk is a creamy, usually yellow 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. As a new mother begins to produce transitional milk, she typically notices an increase in the weight and size of her breasts and a change in the volume and type of liquid secreted.[17]

Mature milk is the final milk that a new mother produces. Its composition varies from morning to night, from the beginning of the feeding to the end, and from early postpartum to later in infancy and toddlerhood. Breastmilk that is produced by mothers of premature infants is higher in protein and calcium to meet the needs of the preemie. Foremilk (the milk that comes at the beginning of a feeding) tends to be lower in fat. Hind-milk comes towards the end of a feeding containing higher levels of fat, which helps the baby to feel satisfied and full. Combined, these two types of milk ensure that a baby receives adequate nutrients to grow and develop properly.[18]

About 87.5 percent of mature milk is water, which helps an infant remain hydrated. The other 12.5 percent contains carbohydrates, proteins, fats, vitamins and minerals which support energy and growth. Similar to cow's milk, the main carbohydrate of mature breast milk is lactose. Breast milk contains the essential fatty acids, linoleic acid and alpha-linolenic acid, and other fats that are important for development such as docosahexaenoic acid (DHA). In terms of protein, breast milk contains more whey than casein (which is the reverse of cow's milk). Whey is much easier for infants to digest than casein. Casein and whey make a complete protein with all of the essential amino acids. Another protein in breastmilk, lactoferrin is an iron-binding protein that helps keep iron away from pathogenic bacteria and facilitates the absorption of iron into an infant's bloodstream.

For most vitamins and minerals, breast milk provides adequate amounts for growth and maintenance of optimal health. Although the absolute amounts of some micronutrients are low, they are more efficiently absorbed by infants from breast milk. Other essential components include digestive enzymes that help a baby digest the breast milk. Human milk also provides the hormones and growth factors that help a newborn to develop.

Diet and Milk Quality

A mother's health habits can impact milk production and quality. As during pregnancy, lactating mothers should avoid illegal substances and cigarettes. Some legal drugs and herbal products can be harmful as well, so it is helpful to discuss them with a healthcare professional. In some rare cases, mothers may need to avoid certain things, such as dairy or spicy foods, that can produce gas in sensitive infants. Lactating women can drink alcohol, though they must avoid breastfeeding until the alcohol has completely cleared from their milk. Typically, this takes two to three hours for 12 ounces of beer, 5 ounces of wine, or 1.5 ounces of liquor, depending on a woman's body weight.[19] Precautions are necessary because exposure to alcohol can negatively affect infant growth.

Benefits of Breastfeeding

Breastfeeding has a number of benefits, both for the mother and for the child. Breast milk contains immunoglobulins, enzymes, immune factors, and white blood cells. As a result, breastfeeding boosts the baby's immune system and lowers the incidence of diarrhea, respiratory diseases, gastrointestinal infections, and ear infections. Breastfed babies also are less likely to develop asthma and allergies, and breastfeeding lowers the risk of sudden infant death syndrome. In addition, human milk encourages the growth of a healthy microbiome (the bacteria in an infant's intestinal tract). Most of these benefits remain after an infant has been weaned from breast milk. Some studies suggest other possible long-term effects. For example, breast milk may improve an infant's intelligence and protect against Type 1 diabetes and obesity, although research is ongoing in these areas.[20]

Breastfeeding has a number of other important benefits. It is easier for babies to digest breast milk than infant formula, which contains proteins made from cow's milk or soybeans that are harder to tolerate. Breastfed infants are sick less often than bottle-fed infants. Breastfeeding is more sustainable and results in less plastic waste and other trash. Breastfeeding can also save families money because it typically saves over $1,200 per year in the US over purchasing formula. Other benefits include that breast milk is always ready. It does not have to be mixed, heated, or prepared. Also, breast milk is sterile and is always at the right temperature.

In addition, the skin-to-skin contact of breastfeeding promotes a close bond between mother and baby, which is an important emotional and psychological benefit. The practice also provides health benefits for the mother. Breastfeeding reduces the risk of Type 2 Diabetes in the mother and infant. Studies have also shown that breastfeeding reduces the risk of breast and ovarian cancers.[21]

The Baby-Friendly Hospital Initiative

In 1991, the WHO and UNICEF launched the Baby-Friendly Hospital Initiative (BFHI), which works to ensure that all maternity care facilities, including hospitals and free-standing facilities, become centers of breastfeeding support. A maternity care facility can be denoted as "baby-friendly" when it does not accept free infant formula and has implemented The Ten Steps to Successful Breastfeeding. These steps include having a written policy on breastfeeding communicated to health-care staff on a routine basis, informing all new mothers about the benefits and management of breastfeeding, showing new mothers how to breastfeed their infants, and how to maintain lactation, and giving newborns no food or drink other than breast milk, unless medically indicated. Since the BFHI began, more than fifteen thousand facilities in 134 countries, from Benin to Bangladesh, have been deemed "baby friendly." As a result, more mothers are breastfeeding their newborns and infant health has improved, in both the developed world and in developing nations.[22] For information on the Baby-Friendly Initiative in the US, see: https://www.babyfriendlyusa.org.

Barriers to Breastfeeding

Although breast milk is ideal for almost all infants, there are some challenges that nursing mothers may face when starting and continuing to breastfeed their infants. These obstacles include painful engorgement or fullness in the breasts, often around day 3 to 5 postpartum, sore and tender nipples, lack of comfort or confidence in public, and lack of accommodation to breastfeed or express milk in the workplace.

One of the first challenges nursing mothers face is learning how to comfortably position the baby at her breast. Improper position and latching usually results in pain for the mother and inadequate intake for the infant, which could slow growth and development. However, all International Board Certified Lactation Consultants (IBCLCs) and most Obstetric nurses are trained to help new mothers learn the proper technique. Some registered dietitians are trained in lactation support as well. A very helpful position for new mothers is called the "Laid-Back Nursing" position, and it usually helps mother and baby to feel more comfortable, and helps baby to latch on without causing any nipple pain. Resources on the laid back position can be found here: https://lllusa.org/lie-back-and-relax-a-look-at-laid-back-breastfeeding/

Education, the length of maternity leave, and laws to protect public breastfeeding, among other measures, can all help to facilitate breastfeeding for many lactating women and their newborns.

Contraindications to Breastfeeding

Although there are numerous benefits to breastfeeding, in some cases there are also risks that must be considered. As of 2025, the guidance around breastfeeding for mothers with HIV in high-income countries has evolved and become more nuanced. Historically, the guidance was clear: **do not breastfeed if you are HIV-positive**, because HIV can be transmitted through breast milk. However, **recent evidence and updated guidelines** now recognize that:

- If a mother is **on effective antiretroviral therapy (ART)**,
- Has a **sustained undetectable viral load** (generally for at least 6 months),
- And is closely monitored by a healthcare team,

→ then the **risk of transmission through breastfeeding is extremely low**, (though **not zero)**.

As of 2023, the US Centers for Disease Control and Prevention updated its stance to **not automatically discourage** breastfeeding if the mother:

- Has an undetectable viral load,

- Is adherent to ART,
- And is fully informed of the risks and benefits.

With effective ART and an undetectable viral load, breastfeeding may be an option under close medical supervision, though the decision should be made on a case-by-case basis with a healthcare provider.

However, in low-income countries where HIV infection rates are high and acceptable infant formula can be difficult to find, many newborns would be deprived of the nutrients they need to develop and grow. Also, inappropriate or contaminated infant formulas cause 1.5 million infant deaths each year. As a result, the WHO recommends that women infected with HIV in the developing world should nurse their infants while taking antiretroviral medications to lower the risk of transmission.[23] In any case, combination feeding (formula and breastmilk together) is not recommended for mothers who are HIV positive because the risk of transmitting HIV to the infant is higher than either breastfeeding or formula feeding alone.

Breastfeeding also is not recommended for women undergoing radiation or chemotherapy treatment for cancer. Additionally, if an infant is diagnosed with galactosemia, meaning an inability to process the simple sugar galactose, the child must be on a galactose-free diet, which excludes breast milk. This genetic disorder is a very rare condition, however, and only affects 1 in thirty- to sixty-thousand newborns.[24] When breastfeeding is contraindicated for any reason, feeding a baby formula enables parents and caregivers to meet their newborn's nutritional needs.

Bottle-Feeding

Most women can breastfeed when given sufficient education and support. However, as discussed, a small percentage of women are unable to breastfeed their infants, while others choose not to. For parents who choose to bottle-feed, infant formula provides a balance of nutrients. However, not all formulas are the same and there are important considerations that parents and caregivers must weigh. Standard formulas use cow's milk as a base. They have 20 calories per fluid ounce, similar to breast milk, with vitamins and minerals added. Often parents start their babies on soy formula because they incorrectly assume that soy formula will reduce allergies and other health problems, but this is not the case. Soy-based formulas are sometimes given to infants who develop diarrhea, constipation, vomiting, colic, or abdominal pain, but more often these babies are put on hydrolysate formula to address these concerns. Hypoallergenic protein hydrolysate formulas are given to infants who are allergic to cow's milk and soy protein, or who have trouble tolerating them. 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, and makes it less likely to trigger gastrointestinal distress.

Preterm infant formulas are given to premature and low birth weight infants, if breast milk is unavailable. Preterm infant formulas have 24 calories per fluid ounce and are given until the infant reaches a desired weight. These formulas are also higher in protein, calcium, and phosphorus to meet the special needs of premature infants.

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 no preparation. Ready-to-use formulas are used when a safe and sanitary water supply is not available. Ready-to-use formulas are also convenient for traveling.

Most babies need about 2.5 ounces of formula per pound of body weight each day. Therefore, the average infant consumes about 24 fluid ounces of breastmilk or formula per day, or one ounce per hour. If an infant sleeps for 2 hours, they often consume 2 ounces of breastmilk or formula at their next feeding. When preparing formula, parents and caregivers should carefully follow the mixing instructions and safety guidelines, since an infant has an immature immune system. All equipment used in formula preparation should be sterilized for newborns, and especially premature infants. Prepared, unused formula should be refrigerated to prevent bacterial growth. A partially finished bottle of infant formula should be discarded after 1 hour. Parents must make sure not to use contaminated water to mix formula in order to prevent foodborne or other illnesses. Follow the instructions for powdered and concentrated formula carefully—formula that is overly diluted will not provide adequate calories and protein, while overly concentrated formula provides too much protein and too little water which can challenge immature kidneys and lead to dehydration.

Around 6 months of age, infants can start sipping expressed breast milk, infant formula, or water from a cup. By 12 to 14 months

of age, children should be using a cup for all liquids.

It is important to note again that both the American Academy of Pediatrics and the WHO state that breast milk is far superior to infant formula. This table compares the advantages of giving a child breast milk to the disadvantages of using bottle formula.

Table 12.4.2: Breast Milk versus Bottle Formula

Breast Milk	Bottle Formula
Antibodies and lactoferrin in breast milk protect infants.	Formula does not contain immunoprotective factors.
The iron in breast milk is absorbed more easily. Because the iron is bound to lactoferrin, it is not available for bacteria in the gut to use as a growth factor.	Formula contains more iron than breast milk, but it is not absorbed as easily, and the iron is a growth factor for pathogenic microbes.
The feces that babies produce do not smell because breastfed infants have different bacteria in the gut.	The feces that bottle-fed infants produce tends to have a foul-smelling odor.
Breast milk is always available and is always at the correct temperature.	Formula must be prepared, refrigerated for storage, and warmed before it is given to an infant.
Breastfed infants are less likely to have constipation.	Bottle-fed infants are more likely to have constipation.
Breastfeeding ostensibly is free, though purchasing optional supplies such as a pump and bottles to express milk does require some expense.	Formula must be purchased and is expensive, typically costing over $1,200 in the first year.
Breast milk contains the fatty acids DHA and EPA, which are vital for brain and vision development.	Some formulas contain DHA and EPA.

Source: American Pregnancy Association (2019, October 14). *Breastfeeding versus bottle feeding*. http://www.americanpregnancy.org/firstyearoflife/breastfeedingandbottle.html

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12.5: Nutrition in Later Infancy and Toddlerhood

In early infancy, nutrition choices are relatively simple (though not necessarily easy!). When the baby is hungry, it's time to breastfeed or prepare a bottle. But in later infancy and toddlerhood, a baby's food horizons expand. This is an exciting period of learning about foods and how to eat with the rest of the family.

Introducing Solid Foods — Complementary Feeding

Complementary feeding refers to the introduction of solid and semi-solid foods alongside breastmilk as a baby begins to transition to a more varied diet. These foods were historically known as "weaning foods," implying a shift away from breastfeeding; however, the term "complementary foods" is now preferred, as they are meant to complement — not replace — breastmilk, which remains a vital source of energy, nutrients, and immune protection through the child's first two years of life (up to 24 months).

The World Health Organization recommends that babies begin eating some solid foods at 6 months while continuing to breastfeed. In 2022, the American Academy of Pediatrics reinforced WHO's recommendation in its Policy Statement on Breastfeeding and the Use of Human Milk: "*The American Academy of Pediatrics (AAP) recommends exclusive breastfeeding for approximately 6 months after birth. Furthermore, the AAP supports continued breastfeeding, along with appropriate complementary foods introduced at about 6 months, as long as mutually desired by mother and child for 2 years or beyond.*"

Other guidelines offer more flexible advice, recommending that solid foods be introduced sometime between 4 and 6 months, depending on the baby's development, interest in eating solids, and family preferences. Regardless, most babies aren't ready to eat solid foods before 4 months, and starting too soon may increase the risk of obesity. Yet it's also important not to start solids too late, as beyond 6 months, breast milk alone can't support a baby's nutrient requirements.[1]

However, as babies begin to eat solids, breast milk or formula continue to be the nutritional foundation of the diet, reinforcing the concept of complementary feeding — solid foods are meant to complement the nutrients provided by breast milk or formula. Between 6 and 12 months, babies gradually eat more solid foods and less milk so that by 12 months, formula is no longer needed. Breastfeeding mothers are recommended to continue breastfeeding to 24 months or beyond, yet in practice, this can be challenging because of the many barrier breastfeeding moms encounter, addressed previously.

Babies should be developmentally ready to eat solids before trying their first foods. A baby ready for solids should be able to do the following:[1]

- Sit up without support (e.g., in a high chair or lap)
- Open mouth for a spoonful of food and swallow it without gagging or pushing it back out
- Reach for and grasp food or toys and bring them to his or her mouth



The American Academy of Pediatrics recommends beginning with iron-rich foods such as pureed meat or iron-fortified cereal (e.g., rice cereal, oatmeal), as iron is usually the most limiting nutrient at this age, particularly for exclusively breastfed babies. Once these foods are introduced, others can gradually be added to the diet, introducing one at a time to keep an eye out for allergic reactions. Work up to a variety of foods from all of the food groups, as babies are willing to try just about anything at this stage, and this is an opportunity for them to learn about different flavors. You can also gradually increase texture, from pureed to mashed food, then lumpy foods to soft finger foods. By 12 months, most babies can eat most of the foods at the family table, with some modifications to avoid choking hazards.[1,2]

When choosing good complementary foods, there are three main goals: (1) to meet nutrient requirements; (2) to introduce potentially allergenic foods; and (3) to support your baby in learning to eat many different flavors and textures. Parents should be sure to include the following:[1,2]

- **Good sources of iron and zinc**, as both minerals can be limiting for breastfed infants. Good sources include meat, poultry, fish, and iron-fortified cereal. Beans, whole grains, and green vegetables add smaller amounts of iron.
- **Adequate fat** to support babies' rapid growth and brain development. Good sources include whole fat yogurt, avocado, nut butters, and olive oil for cooking vegetables. Fish is also a great food for babies, because it provides both iron and fat, and it's a good source of omega-3 fatty acids like DHA and EPA, which support brain development.
- **A variety of vegetables, fruits, and whole grains,** so that your baby learns to like many different tastes and textures. It may take babies and toddlers 8 to 10 exposures of a new food before they learn to like it, so don't be discouraged if your baby doesn't like some foods right away.

Different cultures have specific food customs. In ancient Hawai'i, poi (pounded taro) was a staple food in the diet and is still popular today due to its familiarity and nutrient-dense structure.



Figure 12.5.5

Poi is high in easily digestible calories, a good source of potassium along with a number of other essential vitamins and minerals. Poi also has many gastrointestinal tract health benefits due to its fiber and probiotic content. With its viscous texture, poi is an excellent first food for infants to consume.

Guidelines for feeding healthy infants from the USDA Infant Nutrition and Feeding Guidelines are adapted in the table below.

Table 12.5.2: Guidelines for Feeding Healthy Infants Birth to 12 Months of Age

Age	Human Milk or infant formula	Grain products	Vegetables	Fruit	Protein-rich foods
Birth – 6 months	Newborns breastfeed 8-12 times/day. Formula fed infants should consume 2-3 ounces of formula every 3-4 hours and by 6 months consume 32 ounces/day.	None	None	None	None
6-8 months	Breastfed infants continue to breastfeed, on demand. Formula-fed infants take in about 24-32 ounces. Amounts vary based on individual assessment. Intake of human milk or formula may decrease as complementary foods increase.	About 1-2 ounces iron-fortified infant cereals, bread, small pieces of crackers	About 2-4 ounces of cooked, plain, strained/pureed/mash vegetables	About 2-4 ounces of plain strained/pureed/mashed fruits	About 1-2 ounces meat, poultry, fish, eggs, cheese, yogurt, or legumes; all are plain strained/pureed/mashed
8-12 months	Guide/encourage breastfeeding mothers and continue to support mothers who choose to breastfeeding beyond 12 months. Formula-fed infants take in about 24 ounces. Amounts vary based on individual nutrition assessment.	About 2-4 ounces iron-fortified infant cereals; other grains: baby crackers, bread, noodles, corn, grits, soft tortilla pieces	About 4-6 ounces, ground/finely chopped/diced	About 4-6 ounces, ground/finely chopped/diced	About 2-4 ounces meat, poultry, fish, eggs, cheese, yogurt, or mashed legumes; all are ground/finely chopped/diced

Source:

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NOTE: These are general guidelines for the healthy, full-term infant per day; serving sizes may vary with individual infants. Start complementary foods when developmentally ready, about 6 months; start with about 0.5-1 ounce.

Food Allergies

There is no need to avoid giving your baby common food allergens, such as peanut, egg, dairy, fish, shellfish, wheat, soy, or tree nuts. In fact, studies indicate that introducing at least some of these foods during the first year can prevent food allergies from developing. The evidence is strongest for peanut allergy. A randomized controlled trial published in 2015, called the Learning Early About Peanut Allergy (LEAP) study, showed that in infants considered high-risk for food allergies, feeding peanut products beginning between 4 and 11 months reduced peanut allergy by 81 percent, compared with waiting to give peanuts until age 5.[3] Similarly, early introduction of egg seems to protect children from developing an egg allergy.[4,5] With any new food, keep an eye out for symptoms of an allergic reaction, such as hives, vomiting, wheezing, and difficulty breathing.[6]

Foods to Avoid in the First Year

- **Cow's milk*** can't match the nutrition provided by breast milk or formula and can cause intestinal bleeding in infants. However, dairy products such as yogurt and cheese are good choices for babies who have started solids. Babies can eat other dairy products, like yogurt and cheese, and cow's milk can be added to the diet at 12 months.
- **Plant-based beverages** such as soy and rice milk aren't formulated for infants, lack key nutrients, and often have added sugar.
- **Juice and sugar-sweetened beverages** have too much sugar. Whole fruit in a developmentally-appropriate form (pureed, mashed, chopped, etc.) is a better choice.
- **Honey** may contain botulism, which can make infants very ill.
- **Unpasteurized dairy products or juices, and raw or undercooked meats or eggs**, which can be contaminated with harmful foodborne pathogens.
- **Added sugar and salt** should be kept to a minimum so that your baby learns to like many different flavors and doesn't develop preferences for very sweet or salty foods.
- **Choking hazards** such as whole nuts, grapes, popcorn, hot dogs, and hard candies should be avoided.

*In contrast to US recommendation to avoid cow's milk in the first year of life, the updated 2023 **WHO Guideline for Complementary Feeding** (co-developed with UNICEF) includes a recommendation for **"milks 6–11 months"**: if infants 6–11 months of age are fed milks other than breast milk, **either formula or animal milk may be used** (conditional recommendation, low certainty of evidence).

Additional Details

- The guideline notes that **dairy products (liquid animal milks, yogurt, etc.) are part of a diverse diet** and can help with nutritional adequacy, especially for children who are not breastfed or have limited intake of other animal-source foods.
- However, the guideline does **not** unequivocally state that *all forms* of dairy (in all amounts or every type) are now recommended from birth through 12 months. The recommendations come with important caveats about **evidence certainty**, **safety**, **preparation and handling**, and **iron status risks**.
- The guideline also acknowledges known risks associated with unfortified cow's milk in infancy (e.g. risk of iron deficiency or occult blood loss) but judges that these risks are small in infants 6–11 months when other complementary foods provide sufficient iron, and under safe practices.

Responsive Feeding and Infant Growth

Regardless of whether infants are fed breast milk or formula, and continuing when they start solid foods, it's important that caregivers use a ***responsive feeding*** approach. Responsive feeding is grounded in 3 steps:[2]

- **The child signals hunger and satiety.** This may occur through vocalizations (e.g., crying, talking), actions (e.g., pointing at food, or turning away when full), and facial expressions.
- **The caregiver recognizes the cues and responds promptly and appropriately.** For example, if the baby seems hungry, he or she is offered food promptly. If the baby turns his or her head or pushes away the breast, bottle, or an offered bite of food, the caregiver does not pressure the baby to eat more.
- **The child experiences a predictable response to his or her signals.**



With breastfeeding, responsive feeding simply means feeding the baby when he or she signals hunger, and the baby usually turns away, spits out the nipple, or falls asleep when full. With bottle-feeding, whether feeding breast milk or formula in a bottle, it's a little trickier. It's human nature to want the baby to finish the bottle that you've prepared, but a responsive feeding approach means that you let the baby decide when he or she has had enough. Pressure to eat more can cause the baby to grow too fast in infancy, which is correlated with becoming overweight or obese later in childhood. When feeding solid foods, the same responsive feeding principles apply, although solids should be offered at predictable meal- and snack-times to avoid constant grazing throughout the day. If babies are offered appropriate, nutrient-dense foods, and fed responsively, parents generally don't need to worry about serving sizes or amounts eaten. They can trust that their babies will eat what they need.[2]

Learning to Self-Feed

With the introduction of solid foods, young children begin to learn how to handle food and how to feed themselves. At six to seven months, infants can use their whole hand to pick up items (this is known as the palmer grasp). They can lift larger items, but picking up smaller pieces of food is difficult. At eight months, a child might be able to use a pincer grasp, which uses fingers to pick up objects. After the age of one, children slowly begin to use utensils to handle their food. Unbreakable dishes and cups are essential, since very young children may play with them or throw them when they become bored with their food.

Is Baby Eating Enough?

The best way to determine if children are getting enough food to eat is to track their growth. Pediatricians and other healthcare providers do this by measuring a child's weight, length, and head circumference at each check-up and plotting their measurements periodically on growth charts from the World Health Organization. Growth charts allow you to compare your child's growth to a population of other healthy children. Sometimes parents worry that if their child is in the 15th percentile for weight, that means she's not growing well, but this isn't the case. Children come in different shapes and sizes, and some grow faster than

others. Thus, a child in the 15th percentile for weight may be a bit smaller than average, but when it comes to body size, the goal is not to be average or above average. The goal is to grow steadily and predictably in a way that is healthy for that individual child. If a child who was previously in the 15th percentile was suddenly measured at the 5th percentile or 50th percentile, that might indicate a health or nutrition problem that warrants further evaluation.[7]

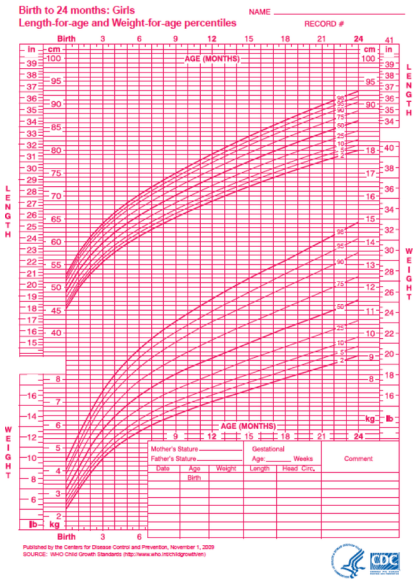


Figure 11.6. WHO growth chart for girls from birth to 24 months.

Feeding Toddlers

Toddlerhood represents a stage of growing independence for children. They gain the physical abilities to feed themselves confidently, and their growing language skills mean they can verbalize food preferences more clearly. Gradually, through exposure and experience, they learn to eat foods more and more like the rest of their family.[8]

In the toddler years, it's important to shift from a mindset of feeding "on demand," which is appropriate for infants, to one of predictable structure, with sit-down meals and snacks (usually three meals and two to three snacks each day). This prevents constant grazing and means that children come to the table hungry, ready to enjoy a nourishing meal. As much as you can, sit down to meals together so that your toddler learns that part of the joy of eating is enjoying time with loved ones.[2,8]

The AMDRs for children ages 1 to 3 recommend that 45 to 65 percent of calories come from carbohydrate, 30 to 40 percent from fat, and 5 to 20 percent from protein. Compared with older children and adults, this balance of macronutrients includes a higher level of fat to support young children's energy demands for growth and development. Therefore, fat or cholesterol generally should not be restricted in toddlers, although the focus should be on nutrient-dense sources of fat. Pediatricians usually recommend that toddlers ages 1 to 2 drink 2 to 3 cups of whole cow's milk per day to provide fat, protein, and micronutrients, including calcium and vitamin D. At age 2, parents can switch to low-fat or nonfat milk to reduce fat intake. For toddlers with a family history or other risk factors for obesity, pediatricians may recommend switching to low-fat milk sooner. It is important for toddlers to not over-consume cow's milk, as filling up on milk will reduce the consumption of other healthful foods. In particular, toddlers who drink too much cow's milk have a greater risk of iron deficiency and iron deficiency anemia, which is a common nutrient for this age group and can cause deficits in brain development.[8]

Just as for adults, MyPlate can be helpful for planning balanced meals for children 2 and up, with appropriate serving sizes. A ballpark recommendation for serving sizes for children ages 2 to 6 is about 1 tablespoon per year of age for each food, with additional food provided based on appetite.[8]

Other recommendations for feeding toddlers include the following:[2,8,9]

- Continuing to offer a variety of foods from all of the food groups, including a mix of vegetables and fruits of different colors, tastes, and textures.

- Include whole grains and protein sources, such as poultry, fish, meats, tofu, or legumes in most meals and snacks.
- Limit salty foods and sugary snacks for health reasons, and so that your child doesn't come to expect these tastes in foods.
- By 12 to 15 months, wean toddlers from a bottle, transitioning to giving milk at meals in a cup. Prolonged bottle use tends to promote overconsumption of milk and can cause dental caries, particularly when toddlers fall asleep with a bottle.
- Continue to take care with choking hazards, as many choking incidents happen in children younger than 4. Common choking hazards include hot dogs, hard candy, nuts, seeds, whole grapes, raw carrots, apples, popcorn, marshmallows, chewing gum, sausages, and globs of peanut butter. Ensuring that children are sitting down when eating can help to prevent choking accidents.
- Stick to cow's milk and water as main beverage choices. Juice can be enjoyed occasionally in small servings (<0.5 cups/day) but is high in sugar, and whole fruit provides more nutrition. Plant-based beverages such as soy milk can be used in the case of a dairy allergy, lactose intolerance, or strong dietary preference, but be aware that these can be high in sugar and may not offer the same nutrients as cow's milk, so check labels carefully. Flavored cow's milk, soda, sports drinks, energy drinks, and caffeinated beverages should be avoided.
- Most children can get all of the nutrients they need from their diet, even if it seems that their intake is variable and they are somewhat picky about their choices. Pediatricians may prescribe a fluoride supplement for children living in areas with low fluoride levels in drinking water. They may also recommend a vitamin D supplement for children who do not consume adequate levels in their diet.

Early Childhood Caries

Primary teeth are at risk for a disorder known as early childhood caries from breast milk, formula, juice, or other drinks fed through a bottle. Liquids can build up in a baby's mouth, and the natural or added sugars lead to decay. Early childhood caries are caused not only by the kinds of liquids given to an infant, but also by the frequency and length of time that fluids are given. Giving a child a bottle of juice or other sweet liquids several times each day, or letting a baby suck on a bottle longer than a mealtime, either when awake or asleep, can also cause early childhood caries. In addition, this practice affects the development and position of the teeth and the jaw. The risk of early childhood caries continues into the toddler years as children begin to consume more foods with a high sugar content. Therefore, parents should avoid putting their children to bed with a bottle, and giving their children sugary snacks and beverages. If a parent insists on giving their child a bottle in bed, then it should be filled with water only.

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CHAPTER 13: NUTRITION DURING CHILDHOOD, ADOLESCENCE AND OLDER AGE

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13.1.2: Toddler Years

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13.1: LIFESPAN NUTRITION DURING CHILDHOOD AND ADOLESCENCE

Learning Objectives

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

- Describe the physiological basis for nutrient requirements during childhood and adolescence.

13.1.1: Introduction

13.1.2: Toddler Years

13.1.3: Childhood

13.1.4: Raising Healthy Eaters

13.1.5: Nutrition in Adolescence

13.1.6: More on Nutrition in Adolescence

13.1.7: Late Adolescence

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13.1.1: Introduction

E mālama ʻia nā pono o ka ʻāina e na ʻōpio

The traditions of the land are perpetuated by its youth

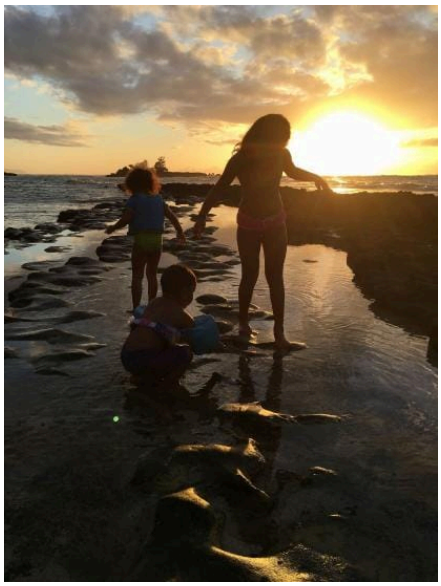


Figure 13.1.1.1: Image by Brytni K-aloha / CC BY 4.0

Early childhood encompasses infancy and the toddler years, from birth through age three. The remaining part of childhood is the period from ages four through eight and is the time when children enter school. A number of critical physiological and emotional changes take place during the life stage from childhood through adolescences. Children's attitudes and opinions about food deepen. They not only begin taking their cues about food preferences from family members, but also from peers and the larger culture. In Hawai'i, organizations such as the Kōkua Hawai'i Foundation have implemented school programs such as 'Āina In Schools to connect children to their local land, waters, and food. The program initiative is to address childhood health issues by fostering healthy eating habits by teaching and engaging youth about local and traditional foods.[1]

Parents also greatly impact their child's nutritional choices. This time in a child's life provides an opportunity for parents and other caregivers to reinforce good eating habits and to introduce new foods into the diet, while remaining mindful of a child's preferences. Parents should also serve as role models for their children, who will often mimic their behavior and eating habits. Parents must continue to help their school-aged children and adolescents establish healthy eating habits and attitudes toward food. Their primary role is to bring a wide variety of health-promoting foods into the home, so that their children can make good choices.

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13.1.2: Toddler Years

Major physiological changes continue into the toddler years. Unlike in infancy, the limbs grow much faster than the trunk, which gives the body a more proportionate appearance. By the end of the third year, a toddler is taller and more slender than an infant, with a more erect posture. As the child grows, bone density increases and bone tissue gradually replaces cartilage. This process known as ossification is not completed until puberty.[1]



Figure 13.1.2.1: Image by kazuend on unsplash.com / CC0

Developmental milestones include running, drawing, toilet training, and self-feeding. How a toddler acts, speaks, learns, and eats offers important clues about their development. By the age of two, children have advanced from infancy and are on their way to becoming school-aged children. Their physical growth and motor development slows compared to the progress they made as infants. However, toddlers experience enormous intellectual, emotional, and social changes. Of course, food and nutrition continue to play an important role in a child's development. During this stage, the diet completely shifts from breastfeeding or bottle-feeding to solid foods along with healthy juices and other liquids. Parents of toddlers also need to be mindful of certain nutrition-related issues that may crop up during this stage of the human life cycle. For example, fluid requirements relative to body size are higher in toddlers than in adults because children are at greater risk of dehydration.

The toddler years pose interesting challenges for parents or other caregivers, as children learn how to eat on their own and begin to develop personal preferences. However, with the proper diet and guidance, toddlers can continue to grow and develop at a healthy rate.

Nutritional Requirements

MyPlate may be used as a guide for the toddler's diet (www.choosemyplate.gov/preschoolers.html). A toddler's serving sizes should be approximately one-quarter that of an adult's. One way to estimate serving sizes for young children is one tablespoon for each year of life. For example, a two-year-old child would be served 2 tablespoons of fruits or vegetables at a meal, while a four-year-old would be given 4 tablespoons, or a quarter cup. Here is an example of a toddler-sized meal:

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

Energy

The energy requirements for ages two to three are about 1,000 to 1,400 calories a day. In general, a toddler needs to consume about 40 calories for every inch of height. For example, a young child who measures 32 inches should take in an average of 1,300 calories a day. However, the recommended caloric intake varies with each child's level of activity. Toddlers require small, frequent, nutritious snacks and meals to satisfy energy requirements. The amount of food a toddler needs from each food group depends on daily calorie needs. See Table 13.1.2.1 for some examples.

Table 13.1.2.1: Serving Sizes for Toddlers

Food Group	Daily Serving	Examples
Grains	About 3-5 ounces of grains per day, ideally whole grains	• 3 slices of bread • 1 slice of bread, plus ⅓ cup of cereal, and ¼ cup of cooked whole-grain rice or pasta
Proteins	2-4 ounces of meat, poultry, fish, eggs, or legumes	• 1 ounce of lean meat or chicken, plus one egg • 1 ounce of fish, plus ¼ cup of cooked beans
Fruits	1-1.5 cups of fresh, frozen, canned, and/or dried fruits, or 100 percent fruit juice	• 1 small apple cut into slices • 1 cup of sliced or cubed fruit • 1 large banana
Vegetables	1-1.5 cups of raw and/or cooked vegetables	• 1 cup of pureed, mashed, or finely chopped vegetables (such as sweet potato, chopped broccoli, or tomato sauce)
Dairy Products	2-2.5 cups per day	• 2 cups of fat-free or low-fat milk • 1 cup of fat-free or low-fat milk, plus 2 slices of cheese • 1 cup of fat-free or low-fat milk, plus 1 cup of yogurt

Source: Hayes, D. (2018, February 20). *It's about eating right: Size-wise nutrition for toddlers*. Academy of Nutrition and Dietetics. https://www.eatright.org/food/nutrit...oler-be-eating

Macronutrients

For carbohydrate intake, the Acceptable Macronutrient Distribution Range (AMDR) is 45 to 65 percent of daily calories (113 to 163 grams for 1,000 daily calories). Toddlers' needs increase to support their body and brain development. The RDA of protein is 5 to 20 percent of daily calories (13 to 50 grams for 1,000 daily calories). The AMDR for fat for toddlers is 30 to 40 percent of daily calories (33 to 44 grams for 1,000 daily calories). Essential fatty acids are vital for the development of the eyes, along with nerve and other types of tissue. However, toddlers should not consume foods with high amounts of trans fats and saturated fats. Instead, young children require the equivalent of 3 teaspoons of healthy oils, such as canola oil, each day.

Micronutrients

As a child grows bigger, the demands for micronutrients increase. These needs for vitamins and minerals can be met with a balanced diet, with a few exceptions. According to the American Academy of Pediatrics, toddlers and children of all ages need 600 international units of vitamin D per day. Vitamin D-fortified milk and cereals can help to meet this need. However, toddlers who do not get enough of this micronutrient should receive a supplement. Pediatricians may also prescribe a fluoride supplement for toddlers who live in areas with fluoride-poor water. Iron deficiency is also a major concern for children between the ages of

two and three. You will learn about iron-deficiency anemia later in this section.

Learning How to Handle Food

As children grow older, they enjoy taking care of themselves, which includes self-feeding. During this phase, it is important to offer children foods that they can handle on their own and that help them avoid choking and other hazards. Examples include fresh fruits that have been sliced into pieces, orange or grapefruit sections, peas or potatoes that have been mashed for safety, a cup of yogurt, and whole-grain bread or bagels cut into pieces. Even with careful preparation and training, the learning process can be messy. As a result, parents and other caregivers can help children learn how to feed themselves by providing the following:

- small utensils that fit a young child's hand
- small cups that will not tip over easily
- plates with edges to prevent food from falling off
- small servings on a plate
- high chairs, booster seats, or cushions to reach a table

Feeding Problems in the Toddler Years

During the toddler years, parents may face a number of problems related to food and nutrition. Possible obstacles include difficulty helping a young child overcome a fear of new foods, or fights over messy habits at the dinner table. Even in the face of problems and confrontations, parents and other caregivers must make sure their preschooler has nutritious choices at every meal. For example, even if a child stubbornly resists eating vegetables, parents should continue to provide them. Before long, the child may change their mind, and develop a taste for foods once abhorred. It is important to remember this is the time to establish or reinforce healthy habits.

Nutritionist Ellyn Satter states that feeding is a responsibility that is split between parent and child. According to Satter, parents are responsible for what their infants eat, while infants are responsible for how much they eat. In the toddler years and beyond, parents are responsible for what they offer their children to eat, when they eat, and where they eat, while children are responsible for how much food they eat and whether they eat. Satter states that the role of a parent or a caregiver in feeding includes the following:

- selecting and preparing food
- providing regular meals and snacks
- making mealtimes pleasant
- showing children what they must learn about mealtime behavior
- avoiding letting children eat in between meal- or snack-times[2]

Picky Eaters

The parents of toddlers are likely to notice a sharp drop in their child's appetite. Children at this stage are often picky about what they want to eat because they just aren't as hungry. They may turn their heads away after eating just a few bites. Or, they may resist coming to the table at mealtimes. They also can be unpredictable about what they want to consume for specific meals or at particular times of the day. Although it may seem as if toddlers should increase their food intake to match their level of activity, there is a good reason for picky eating. A child's growth rate slows after infancy, and toddlers ages two and three do not require as much food.

One way to encourage a picky eater to try healthy foods is to get them involved in age-appropriate tasks in meal preparation. Even small toddlers can tear up lettuce leaves for a salad, or arrange fruit and cheese slices on a plate. Keiki Can Cook! is an online Hawai'i cookbook with healthy recipes for children that highlights tasks for young children. It can be found at: https://health.hawaii.gov/wic/files/2019/03/Cookbook-Keiki-Can-Cook.pdf.

Toddler Obesity

Another potential problem during the early childhood years is toddler obesity. According to the US Department of Health and Human Services, in the past thirty years, obesity rates have more than doubled for all children, including infants and toddlers.[3] Almost 10 percent of infants and toddlers weigh more than they should considering their length, and slightly more than 20 percent

of children ages two to five are overweight or have obesity.[4]

Some minority group children, such as Filipinos, Native Hawaiians, and Other Pacific Islanders, in Hawai'i have higher rates of overweight and obesity. In 2012, 12.8% of Hawai'i WIC (low-income) participants ages two to four years were overweight and 10.2% had obesity.[5][6][7] One study that investigated 2000-2010 data for children ages two to eight years in 51 communities in 11 United States Affiliated Pacific (USAP) jurisdictions found that 14.4% of the study population was overweight and 14% had obesity.[8]

Obesity during early childhood tends to linger as a child matures and cause health problems later in life. There are a number of reasons for this growing problem. One is a lack of time. Parents and other caregivers who are constantly on the go may find it difficult to fit home-cooked meals into a busy schedule and may turn to fast food and other conveniences that are quick and easy, but not nutritionally sound. Another contributing factor is a lack of access to fresh fruits and vegetables. This is a problem particularly in low-income neighborhoods where local stores and markets may not stock fresh produce or may have limited options. Physical inactivity is also a factor, as toddlers who live a sedentary lifestyle are more likely to be overweight or obese. Another contributor is a lack of breastfeeding support. Children who were breastfed as infants have lower rates of obesity than children who were bottle-fed.

To prevent or address toddler obesity parents and caregivers can do the following:

- Eat at the kitchen table instead of in front of a television to monitor what and how much a child eats.
- Offer a child healthy portions. The size of a toddler's fist is an appropriate serving size.
- Plan time for physical activity, about sixty minutes or more per day. Toddlers should have no more than sixty minutes of sedentary activity, such as watching television, per day.

Early Childhood Caries

Early childhood caries remain a potential problem during the toddler years. The risk of early childhood caries continues as children begin to consume more foods with a high sugar content. According to the National Health and Nutrition Examination Survey, children between ages of two and five consume about 200 calories of added sugar per day.[9] Therefore, parents with toddlers should avoid processed foods, such as snacks from vending machines, and sugary beverages, such as soda. Parents also need to instruct a child on brushing their teeth at this time to help a toddler develop healthy habits and avoid tooth decay. Generally, children need help brushing their teeth until they are 5 years old.

Iron-Deficiency Anemia

An infant who switches to solid foods, but does not eat enough iron-rich foods, can develop iron-deficiency anemia. This condition occurs when an iron-deprived body cannot produce enough hemoglobin, a protein in red blood cells that transports oxygen throughout the body. The inadequate supply of hemoglobin for new blood cells results in anemia. Iron-deficiency anemia causes a number of problems including weakness, pale skin, shortness of breath, and irritability. It can also result in intellectual, behavioral, or motor problems. In infants and toddlers, iron-deficiency anemia can occur as young children are weaned from iron-rich foods, such as breast milk and iron-fortified formula. They begin to eat solid foods that may not provide enough of this nutrient. As a result, their iron stores become diminished at a time when this nutrient is critical for brain growth and development.

There are steps that parents and caregivers can take to prevent iron-deficiency anemia, such as adding more iron-rich foods to a child's diet, including lean meats, fish, poultry, eggs, legumes, and iron-enriched whole-grain breads and cereals. A toddler's diet should provide 7 to 10 milligrams of iron daily. Although milk is critical for the bone-building calcium that it provides, intake should not exceed the RDA to avoid displacing foods rich with iron. Children may also be given a daily supplement, using infant vitamin drops with iron or ferrous sulfate drops. If iron-deficiency anemia does occur, treatment includes a dosage of 3 milligrams per kilogram once daily before breakfast, usually in the form of a ferrous sulfate syrup. Consuming vitamin C, such as orange juice, can also help to improve iron absorption.[10]

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13.1.3: Childhood

Nutritional needs change as children leave the toddler years. From ages four to eight, school-aged children grow consistently, but at a slower rate than infants and toddlers. They also experience the loss of deciduous, or “baby,” teeth and the arrival of permanent teeth, which typically begins at age six or seven. As new teeth come in, many children have some malocclusion, or malposition, of their teeth, which can affect their ability to chew food. Other changes that affect nutrition include the influence of peers on dietary choices and the kinds of foods offered by schools and afterschool programs, which can make up a sizable part of a child’s diet. Food-related problems for young children can include tooth decay, food sensitivities, and malnourishment. Also, excessive weight gain early in life can lead to obesity into adolescence and adulthood.

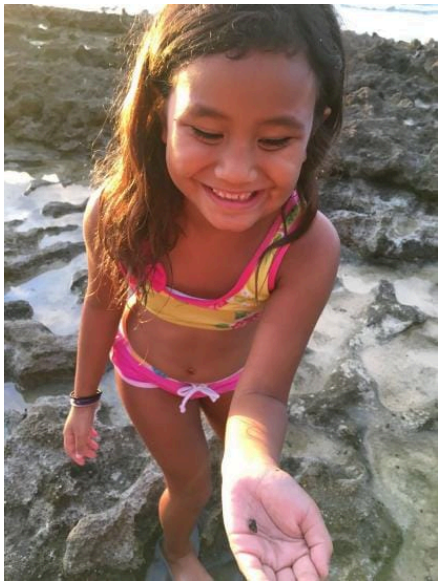


Figure 13.1.3.1: Image by Brytni K-aloha / CC BY 4.0

At this life stage, a healthy diet facilitates physical and mental development and helps to maintain health and wellness. School-aged children experience steady, consistent growth, with an average growth rate of 2–3 inches (5–7 centimeters) in height and 4.5–6.5 pounds (2–3 kilograms) in weight per year. In addition, the rate of growth for the extremities is faster than for the trunk, which results in more adult-like proportions. Long-bone growth stretches muscles and ligaments, which results in many children experiencing “growing pains,” at night, in particular.[1]

Energy

Children’s energy needs vary, depending on their growth and level of physical activity. Energy requirements also vary according to gender. Girls ages four to eight require 1,200 to 1,800 calories a day, while boys need 1,200 to 2,000 calories daily, and, depending on their activity level, maybe more. Also, recommended intakes of macronutrients and most micronutrients are higher relative to body size, compared with nutrient needs during adulthood. Therefore, children should be provided nutrient-dense food at meal- and snack-time. However, it is important not to overfeed children, as this can lead to childhood obesity, which is discussed in the next section. Parents and other caregivers can turn to the MyPlate website for guidance: http://www.choosemyplate.gov/.

Macronutrients

For carbohydrates, the Acceptable Macronutrient Distribution Range (AMDR) is 45–65 percent of daily calories (which is a recommended daily allowance of 135–195 grams for 1,200 daily calories). Carbohydrates high in fiber should make up the bulk of intake. The AMDR for protein is 10–30 percent of daily calories (30–90 grams for 1,200 daily calories). Children have a high need for protein to support muscle growth and development. High levels of essential fatty acids are needed to support growth (although not as high as in infancy and the toddler years). As a result, the AMDR for fat is 25–35 percent of daily calories (33–47

grams for 1,200 daily calories). Children should get 17–25 grams of fiber per day.

Micronutrients

Micronutrient needs should be met with foods first. Parents and caregivers should select a variety of foods from each food group to ensure that nutritional requirements are met. Because children grow rapidly, they require foods that are high in iron, such as lean meats, legumes, fish, poultry, and iron-enriched cereals. Adequate fluoride is crucial to support strong teeth. One of the most important micronutrient requirements during childhood is adequate calcium and vitamin D intake. Both are needed to build dense bones and a strong skeleton. Children who do not consume adequate vitamin D should be given a supplement of 10 micrograms (400 international units) per day. Table 13.1.3.1 shows the micronutrient recommendations for school-aged children. (Note that the recommendations are the same for boys and girls. As we progress through the different stages of the human life cycle, there will be some differences between males and females regarding micronutrient needs.)

Table 13.1.3.1: Micronutrient Levels during Childhood

Nutrient	Children, Ages 4–8
Vitamin A (mcg)	400.0
Vitamin B6 (mcg)	600.0
Vitamin B12 (mcg)	1.2
Vitamin C (mg)	25.0
Vitamin D (mcg)	5.0
Vitamin E (mg)	7.0
Vitamin K (mcg)	55.0
Calcium (mg)	800.0
Folate (mcg)	200.0
Iron (mg)	10.0
Magnesium (mg)	130.0
Niacin(B3) (mg)	8.0
Phosphorus (mg)	500.0
Riboflavin (B2) (mcg)	600.0

Nutrient	Children, Ages 4–8
Selenium (mcg)	30.0
Thiamine (B1) (mcg)	600.0
Zinc (mg)	5.0

Source: Institute of Medicine. 2006. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Washington, DC: The National Academies Press. https://doi.org/10.17226/11537. Accessed December 10, 2017.

Factors Influencing Intake

A number of factors can influence children's eating habits and attitudes toward food. Family environment, societal trends, taste preferences, and messages in the media all impact the emotions that children develop in relation to their diet. Television commercials can entice children to consume sugary products, fatty fast-foods, excess calories, refined ingredients, and sodium. Therefore, it is critical that parents and caregivers direct children toward healthy choices.

One way to encourage children to eat healthy foods is to make meal- and snack-time fun and interesting. Parents should include children in food planning and preparation, for example selecting items while grocery shopping or helping to prepare part of a meal, such as making a salad. At this time, parents can also educate children about kitchen safety. It might be helpful to cut sandwiches, meats, or pancakes into small or interesting shapes. In addition, parents should offer nutritious desserts, such as fresh fruits, instead of calorie-laden cookies, cakes, salty snacks, and ice cream. Also, studies show that children who eat family meals on a frequent basis consume more nutritious foods.[2]

Children and Malnutrition

Malnutrition is a problem many children face, in both developing nations and the developed world. Even with the wealth of food in North America, many children grow up malnourished, or even hungry. The US Census Bureau characterizes households into the following groups:

- food secure
- food insecure without hunger
- food insecure with moderate hunger
- food insecure with severe hunger

Millions of children grow up in food-insecure households with inadequate diets due to both the amount of available food and the quality of food. In the United States, about 20 percent of households with children are food insecure to some degree. In half of those, only adults experience food insecurity, while in the other half both adults and children are considered to be food insecure, which means that children did not have access to adequate, nutritious meals at times.[3]

Growing up in a food-insecure household can lead to a number of problems. Deficiencies in iron, zinc, protein, and vitamin A can result in stunted growth, illness, and limited development. Federal programs, such as the National School Lunch Program, the School Breakfast Program, and Summer Feeding Programs, work to address the risk of hunger and malnutrition in school-aged

children. They help to fill the gaps and provide children living in food-insecure households with greater access to nutritious meals.

The National School Lunch Program

Beginning with preschool, children consume at least one of their meals in a school setting. Many children receive both breakfast and lunch outside of the home. Therefore, it is important for schools to provide meals that are nutritionally sound. In the United States, more than thirty-one million children from low-income families are given meals provided by the National School Lunch Program. This federally-funded program offers low-cost or free lunches to schools, and also snacks to after-school facilities. School districts that take part receive subsidies from the US Department of Agriculture (USDA) for every meal they serve. School lunches must meet the 2015 Dietary Guidelines for Americans and need to provide one-third of the RDAs for protein, vitamin A, vitamin C, iron, and calcium. However, local authorities make the decisions about what foods to serve and how they are prepared.[4]

The Healthy School Lunch Campaign works to improve the food served to children in school and to promote children's short- and long-term health by educating government officials, school officials, food-service workers, and parents. Sponsored by the Physicians Committee for Responsible Medicine, this organization encourages schools to offer more low-fat, cholesterol-free options in school cafeterias and in vending machines.[5]

Food Allergies and Food Intolerance

As discussed previously, the development of food allergies is a concern during the toddler years. This remains an issue for school-aged children. Recent studies show that three million children under age eighteen are allergic to at least one type of food.[6]

Some of the most common allergenic foods include peanuts, milk, eggs, soy, wheat, and shellfish. An allergy occurs when a protein in food triggers an immune response, which results in the release of antibodies, histamine, and other defenders that attack foreign bodies. Possible symptoms include itchy skin, hives, abdominal pain, vomiting, diarrhea, and nausea. Symptoms usually develop within minutes to hours after consuming a food allergen. Children can outgrow a food allergy, especially allergies to wheat, milk, eggs, or soy.

Anaphylaxis is a life-threatening reaction that results in difficulty breathing, swelling in the mouth and throat, decreased blood pressure, shock, or even death. Milk, eggs, wheat, soybeans, fish, shellfish, peanuts, and tree nuts are the most likely to trigger this type of response. A dose of the drug epinephrine is often administered via a "pen" to treat a person who goes into anaphylactic shock.[7]

Some children experience a food intolerance, which does not involve an immune response. A food intolerance is marked by unpleasant symptoms that occur after consuming certain foods. Lactose intolerance, though rare in very young children, is one example. Children who suffer from this condition experience an adverse reaction to the lactose in milk products. It is a result of the small intestine's inability to produce enough of the enzyme lactase, which is produced by the small intestine. Symptoms of lactose intolerance usually affect the GI tract and can include bloating, abdominal pain, gas, nausea, and diarrhea. An intolerance is best managed by making dietary changes and avoiding any foods that trigger the reaction.[8]

The Threat of Lead Toxicity

There is a danger of lead toxicity, or lead poisoning, among school-aged children. Lead is found in plumbing in old homes, in lead-based paint, and occasionally in the soil. Contaminated food and water can increase exposure and result in hazardous lead levels in the blood. Children under age six are especially vulnerable. They may consume items tainted with lead, such as chipped, lead-based paint. Another common exposure is lead dust in carpets, with the dust flaking off of paint on walls. When children play or roll around on carpets coated with lead, they are in jeopardy. Lead is indestructible, and once it has been ingested it is difficult for the human body to alter or remove it. It can quietly build up in the body for months, or even years, before the onset of symptoms. Lead toxicity can damage the brain and central nervous system, resulting in impaired thinking, reasoning, and perception.

Treatment for lead poisoning includes removing the child from the source of contamination and extracting lead from the body. Extraction may involve chelation therapy, which binds with lead so it can be excreted in urine. Another treatment protocol, EDTA therapy, involves administering a drug called ethylenediaminetetraacetic acid to remove lead from the bloodstream of patients with levels greater than 45 mcg/dL.[9] 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.

Query 13.1.3.1

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13.1.4: Raising Healthy Eaters

> *"Raising a healthy eater takes years. Children learn bite by bite, food by food, meal by meal. The goal of raising a healthy eater is to help your child grow up with positive eating attitudes and behaviors; it is not to get him to eat his peas for tonight's supper ."*
>
> Ellyn Satter, MS, MSSW, RDN



As we discussed previously, what we feed kids is important to ensure that they are meeting their nutrient requirements. But, just as important as WHAT we feed kids, is HOW we feed kids. The structure and environment that parents provide when feeding not only impacts nutrition, but it can also affect weight and behavioral problems. Families who regularly eat together have children who eat more fruits and vegetables, have healthier weights, and are less likely to use drugs, alcohol, or tobacco when they are older.[1]

Family meals have many nutritional, social, and emotional benefits. In this section, we will discuss best practices for providing family meals and raising healthy eaters.

The Division of Responsibility

The gold standard for feeding children is Ellyn Satter's Division of Responsibility (sDOR). Ellyn Satter is a dietitian, family therapist, and internationally recognized authority on eating and feeding. ***The Division of Responsibility*** outlines the optimal relationship between parent and child when it comes to feeding: the parent determines the *what, where, and when* of feeding, and the child chooses *how much* to eat and *whether* to eat from the foods provided.[2]

The parents' jobs with feeding:

- Provide structured, sit-down meals and snacks at predictable times
- Decide what foods will be offered at meals and snacks
- Make mealtimes pleasant
- Teach table manners
- Only offer water between meal and snack times; no other foods or beverages
- Be considerate of food preferences, but don't cater to likes and dislikes
- Trust your child knows how much food to eat and will grow into the body right for them

The child's jobs with feeding:

- Eat the amount of food he or she needs
- Learn to eat a variety of foods that are offered at family meals
- Have good table manners
- Grow into the body that is right for him or her

VIDEO: "FEAST: Division of Responsibility" by United Way for Southeastern Michigan, Youtube (January 23, 2019), 4:22

YouTube Video

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The division of responsibility is built on the trust that children know when they are hungry and full, that they want to eat, and that they want to learn to eat grown-up foods. Parents can best support their child's eating by providing the structure of family sit-down meals and snacks and modeling relaxed, enjoyable eating. The division of responsibility is an authoritative approach, providing structure and limits, but allowing the child autonomy within those limits. At meals and snack times, parents promote children's independence by allowing them to pick and choose foods from what has been made available and deciding how much of each to eat.

As your child learns to eat grown-up foods, every day will look slightly different— some days eating a lot and other days eating very little. Don't cross the division of responsibility and pressure your child to eat more or less of something; this kind of pressure backfires. Pressure can be positive: praise, rewards, bribing, making special food, playing games, or talking about nutrition to encourage kids to eat more of nutritious foods or less of "bad" foods. Pressure can also be negative: restricting, threatening, punishing, shaming, or withholding dessert or fun activities. Instead of pressure, follow the division of responsibility in feeding.

Eating Competence

Eating competence is an evidence-based model that defines the interrelated spectrum of eating attitudes and behaviors.[3] The model is based on the principle that internal cues of hunger, appetite, and satiety are reliable and can be used to inform food selection and guide energy balance and body weight. Satter breaks eating competence down into 4 basic components: (1) eating attitudes; (2) food acceptance attitudes and skills; (3) internal regulation attitudes and skills; and (4) contextual attitudes and skills for providing family meals.

According to Ellyn Satter, "Eating Competence is being positive, comfortable, and flexible with eating as well as matter-of-fact and reliable about getting enough to eat of enjoyable food. Even though they don't worry about what and how much to eat, competent eaters do better nutritionally, are more active, sleep better, and have better lab tests. They are more self-aware and self-accepting, not only with food, but in all ways. To be a competent eater, be relaxed, self-trusting, and joyful about eating, and take good care of yourself with food."[4]



Current nutrition advice often focuses on avoidance of foods and reliance on outside indicators, such as diet plans, to guide eating. Eating competence is the opposite. It encourages us to seek food that is enjoyable and to let internal processes such as hunger and satiety to guide eating.

Eating competence comprises both *permission* and *discipline*.[5]

- ***Permission*** is choosing foods that are enjoyable and eating those foods in amounts that are satisfying, based on hunger, appetite, and satiety.
- ***Discipline*** is providing the structure of regular meals and sit-down snacks, and paying attention to internal regulators while eating.

In "Secrets of Feeding a Healthy Family: How to Eat, How to Raise Good Eaters, How to Cook," Satter discusses how the eating competence model is built on trust: "Trust in our love of food and good eating; trust in following our inclinations to eat the food we like in amounts that are satisfying; trust that taking time to enjoy eating is time well-spent; trust that taking pleasure in eating supports being healthy; trust that behaving in such a self-respecting way is legitimate."

Today's nutrition advice is often based on control—the opposite of trust. Control is looking to outside instruction for *what* and *how much* to eat. It is sticking to a strict macro or calorie count; it is eating food because it is good for you (even though it is not appealing); it is eating a defined amount of food that is not related to hunger and satiety; and it is restricting food. Control often means restrained eating, and restrained eaters actually consume *more* food when exposed to forbidden foods.[6] Also, when food choices are externally dictated, especially when promoting negative energy balance, the body's physiological and psychological defense mechanisms are activated, which can lead to gaining excess weight and accumulating excess fat after food restriction.[7]

Parents should consider their own eating competence as they work to build eating competence in their children. Do you feel positive about eating and about food? Do you enjoy eating a variety of foods and trying new foods? Do you trust your internal regulators of hunger, appetite, and satiety to guide how much you eat? Do you have structured meals and snacks? It's much more difficult to raise eating competent children if the adults in the family do not model a healthy relationship with food. Many new parents find that having children inspires them to work towards greater eating competence for themselves.

Meal planning is a good place to start when working on building eating competence. Tips for meal planning:[8]

- Start with what your family is currently eating, and cluster those foods into meals and snacks.
- Try to provide food from each of the food groups for meals, and from 2 to 3 groups for snacks (dairy, fruit, vegetable, protein, and grain). Make sure they are foods you like and enjoy.
- Include bread or similar food like rice at every meal. Bread is always an easy-to-like food that family members can choose when they aren't excited about other options. Pair familiar foods with unfamiliar foods and favorite foods with not-so-favorite foods.
- Include fat in food preparation to make foods enjoyable. For meals to be sustainable, they must be satisfying.

- Let everyone choose what tastes good to them from what is provided on the table.

The Picky Eater

All young children can be picky when it comes to food and refuse to try new foods; this is normal behavior. It is only a concern when children get stuck with being picky. Follow the division of responsibility and adjust your expectations. Steer clear of the following traps that can limit food acceptance:

- Catering the menu to only child-friendly foods or favorite foods
- Making a separate meal when your child complains about what is offered
- Asking your child what they want to eat
- Pressuring your child to eat
- Offering food outside of scheduled meal and snack time

The biggest goal with a finicky eater is to not make eating an issue, and to have mealtime be pleasant. Provide the structure of scheduled meals and snacks, and the permission for your child to choose from what is offered, with no pressure.

For more information on how to raise a healthy eater check out the following resources:

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- Satter, E. (2000). *Child of Mine: Feeding with Love and Good Sense*. Boulder, CO: Bull Publishing Company. Ellynsatterinstitute.org

Self-Check:

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13.1.5: Nutrition in Adolescence

Puberty marks the beginning of adolescence, the time between childhood and young adulthood. The DRI recommendations divide adolescence into two age groups: 9 through 13 years, and 14 through 18 years. The onset of puberty brings a number of changes, including the development of the reproductive organs, the onset of menstruation in females, growth spurts, and changing body composition. Fat usually assumes a larger percentage of change in body weight in girls, while teenage boys experience greater muscle and bone development. All of these changes should be supported with sound nutrition.



Nutrient Needs in Adolescence

Energy and Macronutrients

Adequate energy intake is necessary to support the dramatic growth that takes place during adolescence. For ages 9 to 13, girls should consume about 1,400 to 2,200 calories per day, and boys should consume 1,600 to 2,600 calories per day. For ages 14 to 18, girls should consume about 1,800 to 2,400 calories per day, and boys should consume about 2,000 to 3,200 calories per day. Calorie needs vary based on activity level. The extra energy required for physical development during the teenage years should be obtained primarily from nutrient-dense foods instead of empty-calorie foods, to support adequate nutrient intake and a healthy body weight.

For children and adolescents ages 4 through 18, the AMDR for carbohydrates is 45 to 65 percent of daily calories, and most of these calories should come from high-fiber foods such as whole grains. The AMDR for protein is 10 to 30 percent of daily calories, and lean proteins, such as meat, poultry, fish, beans, nuts, and seeds are excellent ways to meet protein needs. The AMDR for fat is 25 to 35 percent of daily calories. The focus should be on unsaturated plant fats to prevent chronic diseases.

Micronutrients

Micronutrient recommendations for adolescents are mostly the same as for adults, though children this age need more of certain minerals. The most important micronutrients for adolescents are calcium, vitamin D, vitamin A, and iron.

- **Calcium** levels increase to 1,300 mg/day during adolescence to support bone growth and prevent osteoporosis later in life. Low-fat dairy products and foods fortified with calcium, such as breakfast cereals and orange juice, are excellent sources of calcium.
- **Iron** needs increase for adolescent girls with the onset of menstruation (15 mg/day for ages 9 to 13 and 18 mg/day for ages 14 to 18). Adolescent boys also need additional iron for the development of lean body mass (11 mg/day for ages 14-18).

- **Vitamin A** is critical to support the rapid development and growth that happens during adolescence. Adequate fruit and vegetable intake meets vitamin A needs.

Common Nutrition-Related Health Concerns in Adolescence

Disordered Eating

Eating disorders involve extreme behaviors related to food and exercise. They encompass a group of conditions marked by under-eating or overeating, as discussed in Unit 7. Eating disorders stem from stress, low self-esteem, and other psychological and emotional issues. They are most prevalent among adolescent girls but have been increasing among adolescent boys in recent years. Because eating disorders often lead to malnourishment, adolescents with eating disorders are deprived of the crucial nutrients their still-growing bodies need. Girls with anorexia experience nutritional and hormonal problems that negatively influence peak bone density, and therefore may be at increased risk for osteoporosis and fracture throughout life.[1] It is important for parents to watch for signs and symptoms of these disorders, including sudden weight loss, lethargy, vomiting after meals, and the use of appetite suppressants. Eating disorders can lead to serious complications or even be fatal if left untreated. Treatment includes cognitive, behavioral, and nutritional therapy.

Obesity

Children need adequate caloric intake for growth, and it is important not to impose very restrictive diets. However, exceeding caloric requirements on a regular basis can lead to childhood obesity, which has become a major problem worldwide. According to the CDC National Center for Health Statistics, the prevalence of obesity was 18.4% for youth ages 6 to11 and 20.6% for youth ages 12 to 19 in 2106.[2]

There are a number of factors that may contribute to this problem, including:

- early life factors, such as lack of breastfeeding support
- larger portion sizes
- limited access to nutrient-rich foods
- increased access to fast foods and vending machines
- declining physical education programs in schools
- insufficient physical activity and a sedentary lifestyle
- media messages encouraging the consumption of unhealthy foods

Children who suffer from obesity are more likely to become overweight or obese adults. Obesity has a profound effect on self-esteem, energy, and activity level. Even more importantly, it is a major risk factor for a number of diseases later in life, including cardiovascular disease, Type 2 diabetes, stroke, hypertension, and certain cancers.[3]

One major contributing factor to childhood obesity is the consumption of added sugars, especially in the form of sugar sweetened beverages.[4] Added sugars include not only sugar added to food at the table, but also ingredients in items such as bread, cookies, cakes, pies, jams, and soft drinks. In addition, sugars are often “hidden” in items added to foods after they’re prepared, such as ketchup, salad dressing, and other condiments. According to the National Center for Health Statistics, young children and adolescents consume an average of 362 calories per day from added sugars, or about 16% of daily calories, 10% more than what the Dietary Guidelines for Americans recommends.[5] Adolescent boys (ages 12 to19 years) have the greatest intake of added sugar, averaging 442 calories. The primary offenders are processed and packaged foods, along with soda and other beverages. These foods are not only high in sugar, they are also light in terms of nutrients and often take the place of healthier options.



If a child gains weight inappropriate to growth, parents and caregivers should nurture eating competence and follow the division of responsibility as previously discussed in this unit. In addition, it is extremely beneficial to increase a child's physical activity and limit sedentary activities, such as watching television, playing video games, or surfing the Internet. Programs to address childhood obesity can include behavior modification, exercise counseling, psychological support or therapy, family counseling, and family meal-planning advice. For most, the goal is not weight loss, but rather allowing height to catch up with weight as the child continues to grow. Rapid weight loss is not recommended for preteens or younger children due to the risk of deficiencies and stunted growth.

Nutritionally Vulnerable

One of the psychological and emotional changes that takes place during this life stage includes the desire for independence as adolescents develop individual identities apart from their families. One way that teenagers assert their independence is by choosing what to eat. They have their own money to purchase food and tend to eat more meals away from home. Too many poor choices can make young people nutritionally vulnerable.

At this life stage, young people still need the structure of family meals. Evidence shows that eating family meals is associated with nutritional benefits, including eating a diet with more fruits, vegetables, fiber, and micronutrients, and less fried food, soda, and saturated and trans fat.[6]

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13.1.6: More on Nutrition in Adolescence

The onset of puberty is the beginning of adolescence and is the bridge between the childhood years and young adulthood. According to the DRI recommendations, adolescence is divided into two age groups: 9 through 13 years, and 14 through 18 years. Some of the important physiological changes that take place during this stage include the development of primary sex characteristics, or the reproductive organs, along with the onset of menstruation in females. This life stage is also characterized by the appearance of secondary sex characteristics, such as the growth of facial and body hair, the development of breasts in girls, and the deepening of the voice in boys. Other physical changes include rapid growth and alterations in body proportions.[1] All of these changes, as well as the accompanying mental and emotional adjustments, should be supported with sound nutrition.



Figure 13.1.6.1: Image by Peter Hershey on unsplash.com / CC0

The Onset of Puberty (Ages 9 through 13 years)

This period of physical development is divided into two phases. The first phase involves height increases from 20 to 25 percent. Puberty is second to the prenatal period in terms of rapid growth as the long bones stretch to their final, adult size. Girls grow 2–8 inches (5–20 centimeters) taller, while boys grow 4–12 inches (10–30 centimeters) taller. The second phase involves weight gain related to the development of bone, muscle, and fat tissue. Also in the midst of puberty, the sex hormones trigger the development of reproductive organs and secondary sexual characteristics, such as pubic hair. Girls also develop “curves,” while boys become broader and more muscular.[2]

Energy and Macronutrients

The energy requirements for preteens differ according to gender, growth, and activity level. For ages nine to thirteen, girls should consume about 1,400 to 2,200 calories per day and boys should consume 1,600 to 2,600 calories per day. Physically active preteens who regularly participate in sports or exercise need to eat a greater number of calories to account for increased energy expenditures.

For carbohydrates, the AMDR is 45 to 65 percent of daily calories (which is a recommended daily allowance of 158–228 grams for 1,400–1,600 daily calories). Carbohydrates that are high in fiber should make up the bulk of intake. The AMDR for protein is 10 to 30 percent of daily calories (35–105 grams for 1,400 daily calories for girls and 40–120 grams for 1,600 daily calories for boys). The AMDR for fat is 25 to 35 percent of daily calories (39–54 grams for 1,400 daily calories for girls and 44–62 grams for 1,600 daily calories for boys), depending on caloric intake and activity level.

Micronutrients

Key vitamins needed during puberty include vitamins D, K, and B_{12}. Adequate calcium intake is essential for building bone and preventing osteoporosis later in life. Adolescents have the highest 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). Table 13.1.6.1 shows the micronutrient recommendations for young adolescents.

Table 13.1.6.1: Micronutrient Levels during Puberty

Nutrient	Preteens, Ages 9–13
Vitamin A (mcg)	600.0
Vitamin B6 (mg)	1.0
Vitamin B12 (mcg)	1.8
Vitamin C (mg)	45.0
Vitamin D (mcg)	5.0
Vitamin E (mg)	11.0
Vitamin K (mcg)	60.0
Calcium (mg)	1,300.0
Folate (mcg)	300.0
Iron (mg)	8.0
Magnesium (mg)	240.0
Niacin (B3) (mg)	12.0
Phosphorus (mg)	1,250.0
Riboflavin (B2) (mcg)	900.0
Selenium (mcg)	40.0
Thiamine (B1) (mcg)	900.0
Zinc (mg)	8.0

Source: Institute of Medicine. 2006. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Washington, DC: The National Academies Press. https://doi.org/10.17226/11537. Accessed December 10, 2017.

Considerations for Transgender and Gender-diverse Adolescents

In growing adolescents or youth, BMI-for-age percentiles remain relevant, but caution is warranted when applying sex-based percentile curves if puberty blockers or gender-affirming hormone therapy has altered growth trajectories (Gold et al., 2024).

Biochemical tests, clinical labs, and imaging: A comprehensive biochemical panel is essential to guide personalized nutrition care in transgender individuals. Important tests and measures include:

- **Hemoglobin / hematocrit**: To screen for anemia or polycythemia; testosterone therapy often increases hemoglobin/hematocrit, whereas estrogen regimens might reduce it (Linsenmeyer et al., 2020).
- **Ferritin / iron panel**: To assess iron stores; if menses are suppressed, iron needs may decline, but supplementation risks should be weighed against labs. (Sousa et al., 2024)
- **Lipid profile (HDL, LDL, total cholesterol, triglycerides)**: Hormone therapy may shift lipids (e.g. reductions in HDL with some estrogen regimens, increases in LDL) (Linsenmeyer et al., 2020)

- **Glucose, insulin, HbA1c**: To monitor metabolic risk, as hormone therapy or changes in body composition may influence insulin sensitivity. (Gold et al., 2024)
- **Liver function tests, kidney function, electrolytes**: As per standard metabolic panels.
- **Bone mineral density (BMD) / DXA**: Particularly important in those undergoing gonadal suppression or inconsistent hormone therapy, given risk of bone loss. Hormone therapy is generally associated with stable or increased BMD, but monitoring is prudent (Gold et al., 2024; Linsenmeyer et al., 2020)
- **Vitamin D, calcium, parathyroid hormone**: To support bone health, especially in the context of potential hypogonadism. (Gold et al., 2024)
- **Other nutrient biomarkers as indicated**: e.g. B12, folate, zinc, magnesium, depending on diet history, supplementation, or symptoms (Anderson & Nye, 2022)

Integrating these considerations to tailor macronutrient and micronutrient goals, monitor for unintended weight gain or loss, and guard against disordered eating risks (which are disproportionately elevated in transgender populations) (Linsenmeyer, 2024) supports good gender-affirming nutrition care.

Gender-affirming nutrition care demands flexibility: selecting or blending reference values based on hormonal state, tracking body composition changes rather than overreliance on rigid cutoffs, and anchoring nutrient recommendations in individualized lab data. Because the evidence base remains limited, ongoing data collection, research, and shared decision-making with clients are foundational to advancing best practice in this domain (Sousa et al., 2023; Gold et al., 2024).

YouTube Video

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Video: Nutrition Assessment for Transgender and Gender-Diverse Patients — What's in a Number? by **Dietitians in Nutrition Support** YouTube (May 27, 2025), 20:21. Join Dr. Jennifer Waters and Dr. Whitney Linsenmeyer as they share about best practices for conducting a nutrition assessment with patients or clients who identify as transgender or gender-diverse. They will share about gender-affirming communication as well as gender-affirming treatments, including hormone regimens and their impact on biochemical markers.

Query 13.1.6.1

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13.1.7: Late Adolescence

After puberty, the rate of physical growth slows down. Girls stop growing taller around age sixteen, while boys continue to grow taller until ages eighteen to twenty. One of the psychological and emotional changes that takes place during this life stage includes the desire for independence as adolescents develop individual identities apart from their families.[1] As teenagers make more and more of their dietary decisions, parents or other caregivers and authority figures should guide them toward appropriate, nutritious choices. One way that teenagers assert their independence is by choosing what to eat. They have their own money to purchase food and tend to eat more meals away from home. Older adolescents also can be curious and open to new ideas, which includes trying new kinds of food and experimenting with their diet. For example, teens will sometimes skip a main meal and snack instead. That is not necessarily problematic. Their choice of food is more important than the time or place.



Figure 13.1.7.1: Image by Riley McCullough on unsplash.com / CC0

However, too many poor choices can make young people nutritionally vulnerable. Teens should be discouraged from eating fast food, which has a high fat and sugar content, or frequenting convenience stores and using vending machines, which typically offer poor nutritional selections. Other challenges that teens may face include obesity and eating disorders. At this life stage, young people still need guidance from parents and other caregivers about nutrition-related matters. It can be helpful to explain to young people how healthy eating habits can support activities they enjoy, such as skateboarding or dancing, or connect to their desires or interests, such as a lean figure, athletic performance, or improved cognition.

As during puberty, growth and development during adolescence differs in males than in females. In teenage girls, fat assumes a larger percentage of body weight, while teenage boys experience greater muscle and bone increases. For both, primary and secondary sex characteristics have fully developed and the rate of growth slows with the end of puberty. Also, the motor functions of an older adolescent are comparable to those of an adult.[2] Again, adequate nutrition and healthy choices support this stage of growth and development.

Energy and Macronutrients

Adolescents have increased appetites due to increased nutritional requirements. Nutrient needs are greater in adolescence than at any other time in the life cycle, except during pregnancy. The energy requirements for ages fourteen to eighteen are 1,800 to 2,400 calories for girls and 2,000 to 3,200 calories for boys, depending on activity level. The extra energy required for physical development during the teenaged years should be obtained from foods that provide nutrients instead of “empty calories.” Also, teens who participate in sports must make sure to meet their increased energy needs.

Older adolescents are more responsible for their dietary choices than younger children, but parents and caregivers must make sure that teens continue to meet their nutrient needs. For carbohydrates, the AMDR is 45 to 65 percent of daily calories (203–293

grams for 1,800 daily calories). Adolescents require more servings of grain than younger children, and should eat whole grains, such as wheat, oats, barley, and brown rice. The Institute of Medicine recommends higher intakes of protein for growth in the adolescent population. The AMDR for protein is 10 to 30 percent of daily calories (45–135 grams for 1,800 daily calories), and lean proteins, such as meat, poultry, fish, beans, nuts, and seeds are excellent ways to meet those nutritional needs.

The AMDR for fat is 25 to 35 percent of daily calories (50–70 grams for 1,800 daily calories), and the AMDR for fiber is 25–34 grams per day, depending on daily calories and activity level. It is essential for young athletes and other physically active teens to intake enough fluids, because they are at a higher risk for becoming dehydrated.

Micronutrients

Micronutrient recommendations for adolescents are mostly the same as for adults, though children this age need more of certain minerals to promote bone growth (e.g., calcium and phosphorus, along with iron and zinc for girls). Again, vitamins and minerals should be obtained from food first, with supplementation for certain micronutrients only (such as iron).

The most important micronutrients for adolescents are calcium, vitamin D, vitamin A, and iron. Adequate calcium and vitamin D are essential for building bone mass. The recommendation for calcium is 1,300 milligrams for both boys and girls. Low-fat milk and cheeses are excellent sources of calcium and help young people avoid saturated fat and cholesterol. It can also be helpful for adolescents to consume products fortified with calcium, such as breakfast cereals and orange juice. Iron supports the growth of muscle and lean body mass. Adolescent girls also need to ensure sufficient iron intake as they start to menstruate. Girls ages twelve to eighteen require 15 milligrams of iron per day. Increased amounts of vitamin C from orange juice and other sources can aid in iron absorption. Also, adequate fruit and vegetable intake allows for meeting vitamin A needs. Table 13.1.7.1 shows the micronutrient recommendations for older adolescents, which differ slightly for males and females, unlike the recommendations for puberty.

Table 13.1.7.1: Micronutrient Levels during Older Adolescence

Nutrient	Males, Ages 14–18	Females, Ages 14–18
Vitamin A (mcg)	900.0	700.0
Vitamin B6 (mg)	1.3	1.2
Vitamin B12 (mcg)	2.4	2.4
Vitamin C (mg)	75.0	65.0
Vitamin D (mcg)	5.0	5.0
Vitamin E (mg)	15.0	15.0
Vitamin K (mcg)	75.0	75.0
Calcium (mg)	1,300.0	1,300.0
Folate mcg)	400.0	400.0
Iron (mg)	11.0	15.0
Magnesium (mg)	410.0	360.0
Niacin (B3) (mg)	16.0	14.0
Phosphorus (mg)	1,250.0	1,250.0
Riboflavin (B2) (mg)	1.3	1.0
Selenium (mcg)	55.0	55.0
Thiamine (B1) (mg)	1.2	1.0
Zinc (mg)	11.0	9.0

Source: Institute of Medicine. 2006. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Washington, DC: The National Academies Press. https://doi.org/10.17226/11537. Accessed December 10, 2017.

Eating Disorders

Many teens struggle with an eating disorder, which can have a detrimental effect on diet and health. A study published by North Dakota State University estimates that these conditions impact twenty-four million people in the United States and seventy million worldwide.[3] These disorders are more prevalent among adolescent girls, but have been increasing among adolescent boys in recent years. Because eating disorders often lead to malnourishment, adolescents with an eating disorder are deprived of the crucial nutrients their still-growing bodies need.

Eating disorders involve extreme behavior related to food and exercise. Sometimes referred to as "starving or stuffing," they encompass a group of conditions marked by under eating or overeating. Some of these conditions include:

- **Anorexia Nervosa.** Anorexia nervosa is a potentially fatal condition characterized by under eating and excessive weight loss. People with this disorder are preoccupied with dieting, calories, and food intake to an unhealthy degree. Anorexics have a poor body image, which leads to anxiety, avoidance of food, a rigid exercise regimen, fasting, and a denial of hunger. The condition predominantly affects females. Between 0.5 and 1 percent of American women and girls suffer from this eating disorder.
- **Binge-Eating Disorder.** People who suffer from binge-eating disorder experience regular episodes of eating an extremely large amount of food in a short period of time. Binge eating is a compulsive behavior, and people who suffer from it typically feel it is beyond their control. This behavior often causes feelings of shame and embarrassment, and leads to obesity, high blood pressure, high cholesterol levels, Type 2 diabetes, and other health problems. Both males and females suffer from binge-eating disorder. It affects 1 to 5 percent of the population.
- **Bulimia Nervosa.** Bulimia nervosa is characterized by alternating cycles of overeating and undereating. People who suffer from it partake in binge eating, followed by compensatory behavior, such as self-induced vomiting, laxative use, and compulsive exercise. As with anorexia, most people with this condition are female. Approximately 1 to 2 percent of American women and girls have this eating disorder.[4]

Eating disorders stem from stress, low self-esteem, and other psychological and emotional issues. It is important for parents to watch for signs and symptoms of these disorders, including sudden weight loss, lethargy, vomiting after meals, and the use of appetite suppressants. Eating disorders can lead to serious complications or even be fatal if left untreated. Treatment includes cognitive, behavioral, and nutritional therapy.

Childhood and Adolescent Obesity

Children need adequate caloric intake for growth, and it is important not to impose very restrictive diets. However, exceeding caloric requirements on a regular basis can lead to childhood obesity, which has become a major problem in North America. Nearly one of three US children and adolescents are overweight or obese.[5]

There are a number of reasons behind this problem, including:

- larger portion sizes
- limited access to nutrient-rich foods
- increased access to fast foods and vending machines
- lack of breastfeeding support
- declining physical education programs in schools
- insufficient physical activity and a sedentary lifestyle
- media messages encouraging the consumption of unhealthy foods

Children who suffer from obesity are more likely to become overweight or obese adults. Obesity has a profound effect on self-esteem, energy, and activity level. Even more importantly, it is a major risk factor for a number of diseases later in life, including cardiovascular disease, Type 2 diabetes, stroke, hypertension, and certain cancers.[6]

A percentile for body mass index (BMI) specific to age and sex is used to determine if a child is overweight or obese. This is more appropriate than the BMI categories used for adults because the body composition of children varies as they develop, and differs between boys and girls. If a child gains weight inappropriate to growth, parents and caregivers should limit energy-dense, nutrient-poor snack foods. In addition, it is extremely beneficial to increase a child's physical activity and limit sedentary activities, such as watching television, playing video games, or surfing the Internet.

Programs to address childhood obesity can include behavior modification, exercise counseling, psychological support or therapy, family counseling, and family meal-planning advice. For most, the goal is not weight loss, but rather allowing height to catch up with weight as the child continues to grow. Rapid weight loss is not recommended for preteens or younger children due to the risk of deficiencies and stunted growth.

Avoiding Added Sugars

One major contributing factor to childhood obesity is the consumption of added sugars. Added sugars include not only sugar added to food at the table, but also are ingredients in items such as bread, cookies, cakes, pies, jams, and soft drinks. The added sugar in store-bought items may be listed as white sugar, brown sugar, high-fructose corn syrup, honey, malt syrup, maple syrup, molasses, anhydrous dextrose, crystal dextrose, and concentrated fruit juice. (Not included are sugars that occur naturally in foods, such as the lactose in milk or the fructose in fruits.) In addition, sugars are often “hidden” in items added to foods after they’re prepared, such as ketchup, salad dressing, and other condiments. According to the National Center for Health Statistics, young children and adolescents consume an average of 322 calories per day from added sugars, or about 16 percent of daily calories.[7]

The primary offenders are processed and packaged foods, along with soda and other beverages. These foods are not only high in sugar, they are also light in terms of nutrients and often take the place of healthier options. Intake of added sugar should be limited to 100–150 calories per day to discourage poor eating habits.

Impact of Taxes on Intake of Sugar-Sweetened Beverages (SSBs) — aka 'soda tax'

In efforts to reduce added sugar intake among adolescents, soda taxes in California — particularly in **Berkeley** and **San Francisco** — have shown promising but somewhat mixed results. In Berkeley, which implemented a one-cent-per-ounce excise tax in March 2015, researchers found that in low-income neighborhoods SSB consumption fell about **21%** within months of implementation, while consumption rose about 4% in comparison cities without a tax. Water consumption increased by ~63% in Berkeley versus ~19% in comparison cities. Over a longer horizon, residents in those neighborhoods reported **52% fewer servings** of sugary drinks three years post-tax than before the tax passed. In San Francisco, whose tax took effect more recently, evaluation reports show that sugary drink consumption dropped by about **34%** over two years in citywide samples, with more modest declines (around 13-14 %) in high-volume consumption measures.

When looking specifically at adolescents and youth, data is more limited. A large Kaiser Permanente study comparing cities with SSB taxes (Berkeley, San Francisco, Oakland, Albany) to cities without found that, overall, children and teens in taxed cities had a lower average BMI percentile — approximately 1.64 percentage points lower—after the taxes were adopted. Age-stratified results suggest the effects are greater among younger children (under 12) than among adolescents. Another study using NHANES data exploiting variation in state soda sales taxes found that adolescents do respond to tax increases on soft drinks by reducing soda intake, but often substitute toward other caloric beverages (e.g. milk drinks), resulting in little net change in total sugar intake or in glycemic markers.

Below is a summary table of key studies evaluating the impact of soda taxes in Berkeley and San Francisco, with a focus on outcomes relevant to adolescents and efforts to reduce added sugar intake:

Study	Location	Population	Study Design	Key Outcomes	Relevance to Adolescents
Falbe et al. (2016) Am J Public Health	Berkeley, CA	Low-income adults (18+)	Repeated cross-sectional survey (pre/post tax)	**21% decrease** in SSB consumption in Berkeley; **4% increase** in comparison cities; **63% increase** in water intake	Indirect: adult sample only, but implications for community exposure
Lee et al. (2019) AJPH follow-up	Berkeley, CA	Adults in low-income neighborhoods	3-year follow-up	**52% fewer servings** of SSBs per day; no evidence of business harm	Indirect; adolescent behaviors may be influenced by environmental change

Study	Location	Population	Study Design	Key Outcomes	Relevance to Adolescents
Public Health Institute (2020)PHI report	San Francisco, CA	General population	Cross-sectional surveys (pre/post tax)	**34% drop** in SSB consumption; **13% decrease** in high-consumption group	Mixed age groups; data not stratified by age
Restrepo et al. (2020)NHANES analysis	U.S. national (varying state taxes)	Adolescents (12–19)	Longitudinal dietary data + tax data	Higher taxes linked to **lower soda intake**, but some substitution to other caloric drinks; net **no change** in added sugar intake	Directly measures adolescent intake behavior

In sum, while soda taxes in Berkeley and San Francisco are associated with sizeable drops in sugary drink purchases and self-reported consumption, especially among higher consumers and in low-income neighborhoods, the evidence for adolescent populations — especially for overall added sugar intake, or long-term health outcomes like obesity — is still emerging. The larger effects tend to come from reductions in soda consumption rather than complete elimination of sugar from beverages, and substitution effects are a concern.

Tools for Change

The 2008 *Physical Activity Guidelines for Americans* recommended that preteens and teens engage in at least 60 minutes of moderate to vigorous physical activity each day. This included aerobic exercises, as well as activities that build muscle and strengthen bones. Despite these guidelines, many young people have continued to fall short of these targets. Encouraging preteens to adopt more active lifestyles remains essential in preventing and addressing childhood obesity.

One notable effort to tackle this issue was the *Let's Move!* campaign, launched in 2010 by then–First Lady Michelle Obama. This initiative aimed to combat the growing rates of childhood obesity by promoting physical activity and healthier eating habits. It provided resources for parents and educators, advocated for improved food options in schools and afterschool programs, and encouraged children to engage in physical activities they enjoy — such as biking, playing sports, or dancing. While *Let's Move!* is no longer active, it stands as a key example of previous federal efforts to improve youth health through policy, education, and community engagement. More information about the campaign can still be found at here (https://letsmove.obamawhitehouse.archives.gov/).

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Query 13.1.7.2

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13.2: LIFESPAN NUTRITION IN ADULTHOOD

Learning Objectives

Breakdown by life stage (approximate):

Life Stage	Age Range
Young adulthood	20–39
Middle age	40–65
Older adulthood	65+

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

- Describe the physiological basis for nutrient requirements during adulthood.

13.2.1: Introduction to Lifespan Nutrition in Adulthood

13.2.2: Young Adulthood

13.2.3: Middle Age

13.2.4: Nutrition in Older Adults

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13.2.1: Introduction to Lifespan Nutrition in Adulthood

E ola koa.

Live like a koa tree.

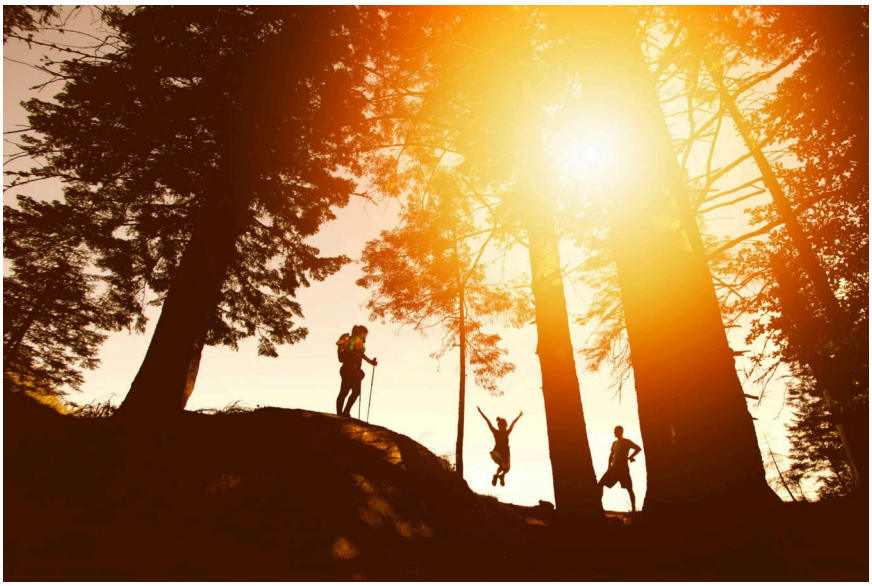


Image by nic.co on unsplash.com / CCO

Adulthood begins at the end of adolescence and continues until the end of one's life. During adulthood, the human body will reach maximum cardiac output specifically between ages twenty and thirty. Bone and muscle mass also reach optimal levels, and physical activity helps to improve muscle strength, endurance, and tone.[1] In order to maintain health and fitness throughout the lifespan, it is important to remain active. The CDC has implemented science based physical activity guidelines for all Americans to follow in hopes of creating a healthy lifestyle. In Hawai'i, nearly 60% of all adults meet the recommended aerobic physical activity guidelines. However, only 32% of adults meet the guidelines for muscle strengthening and less than a quarter (23%) of Hawai'i residents meet the recommended guidelines for both.[2] To learn more about the current physical activity guidelines visit www.cdc.gov/cancer/dcpc/prevention/policies_practices/physical_activity/guidelines.htm.

Along with physical activity, nutrition also plays an essential role in maintaining health through adulthood. As you've already learned, a healthful diet includes a variety of nutrient dense foods. The USDA Dietary Guidelines recommend eating a balanced diet from the five food groups: fruits, vegetables, protein, grains and dairy.[3] In Hawai'i, only about 19% of adults eat the recommended amount of servings of fruits and vegetables per day. Inadequacy of any food group can lead to several health issues.[4] Consuming diets high in fruits and vegetables may have health benefits such as a reduced risk for heart disease, and protection against certain cancers.[5]

Query 13.2.1.1

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13.2.2: Young Adulthood

Young adulthood is the period from ages 20–39 years. It is a stable time compared to childhood and adolescence. Physical growth has been completed and all of the organs and body systems are fully developed. Typically, a young adult who is active has reached his or her physical peak and is in prime health. For example, vital capacity, or the maximum amount of air that the lungs can inhale and exhale, is at its peak between the ages of twenty and forty.[1] During this life stage, it important to continue to practice good nutrition. Healthy eating habits promote metabolic functioning, assist repair and regeneration, and prevent the development of chronic conditions. In addition, the goals of a young adult, such as beginning a career or seeking out romantic relationships, can be supported with good habits. Proper nutrition and adequate physical activity at this stage not only promote wellness in the present, but also provide a solid foundation for the future.



Figure 13.2.2.1: Image by David Marcu on unsplash.com / CC0

With the onset of adulthood, good nutrition can help young adults enjoy an active lifestyle. 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. Some adults have gotten a healthy start and have established a sound diet and regular activity program, which helps them remain in good condition from young adulthood into the later years. Others carry childhood obesity into adulthood, which adversely affects their health. However, it is not too late to change course and develop healthier habits and lifestyle choices. Therefore, adults must monitor their dietary decisions and make sure their caloric intake provides the energy that they require, without going into excess.

Energy and Macronutrients

Young men typically have higher nutrient needs than young women. For ages nineteen to thirty, the energy requirements for women are 1,800 to 2,400 calories, and 2,400 to 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. For carbohydrates, the AMDR is 45 to 65 percent 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 protein is 10 to 35 percent of total daily calories, and should include a variety of lean meat and poultry, eggs, beans, peas, nuts, and seeds. The guidelines also recommend that adults eat two 4-ounce servings (or one 8-ounce serving) of seafood per week.

It is also important to replace proteins that are high in trans fats and saturated fat with ones that are lower in solid fats and calories. All adults should limit total fat to 20 to 35 percent of their daily calories and keep saturated fatty acids to less than 10 percent of total calories by replacing them with monounsaturated and polyunsaturated fatty acids. Avoid trans fats by limiting foods that contain synthetic sources, such as partially hydrogenated oils. The AMDR for fiber is 22 to 28 grams per day for women

and 28 to 34 grams per day for men. Soluble fiber may help improve cholesterol and blood sugar levels, while insoluble fiber can help prevent constipation.

Micronutrients

Micronutrient needs in adults differ slightly according to sex. Young men and women who are very athletic and perspire a great deal also require extra sodium, potassium, and magnesium. Males require more of vitamins C and K, along with thiamine, riboflavin, and niacin. Females require extra iron due to menstruation. Therefore, it can be beneficial for some young adults to follow a daily multivitamin regimen to help meet nutrient needs. But as always, it is important to remember "food first, supplements second." Table 13.2.2.1 shows the micronutrient recommendations for adult men and women.

Table 13.2.2.1*: Micronutrient Levels during Adulthood*

Nutrient	Adult Males	Adult Females
Vitamin A (mcg)	900.0	700.0
Vitamin B_6 (mg)	1.3	1.3
Vitamin B_{12} (mcg)	2.4	2.4
Vitamin C (mg)	90.0	75.0
Vitamin D (mcg)	5.0	5.0
Vitamin E (mg)	15.0	15.0
Vitamin K(mcg)	120.0	90.0
Calcium (mg)	1,000.0	1,000.0
Folate (mcg)	400.0	400.0
Iron (mg)	8.0	18.0
Magnesium (mg)	400.0	310.0
Niacin (mg)	16.0	14.0
Phosphorus (mg)	700.0	700.0
Riboflavin (mg)	1.3	1.1
Selenium	55.0	55.0
Thiamin (mg)	1.2	1.1
Zinc (mg)	11.0	8.0

Source: Institute of Medicine. 2006. Dietary Reference Intakes: The Essential Guide to Nutrient Requirements. Washington, DC: The National Academies Press. https://doi.org/10.17226/11537. Accessed December 10, 2017.

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.[2] 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 2,300 milligrams per day.

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, about two-thirds of all adults in the United States are overweight or obese, with 35.7 percent considered to be obese. [3] As during childhood and adolescence, physical inactivity and poor dietary choices are major contributors to obesity in adulthood. Solid fats, alcohol, and added sugars make up 35 percent of total calories for most people, leading to high levels of saturated fat and cholesterol and insufficient dietary fiber. Therefore, it is important to limit unrefined carbohydrates and processed foods.

Query 13.2.2.1

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13.2.3: Middle Age

Middle age is defined as the period from age 40–65. The early period of this stage is very different from the end. For example, during the early years of middle age, women can still experience pregnancy, childbirth, and lactation. In the latter part of this life stage, women face perimenopause, which is a transition period that leads up to menopause, or the end of menstruation. A number of physical changes take place in the middle-aged years, including the loss of bone mass in women due to dropping levels of estrogen during menopause. In both men and women, visual acuity declines, and starting around age 40 there can be a decreased ability to see objects at a close distance, a condition known as presbyopia.[1] All of these are signs of aging, as the human body begins to change in subtle and not-so-subtle ways. However, a middle aged person can remain vital, healthy, and near his or her physical peak with proper diet and adequate exercise.

During this stage of the human life cycle, adults begin to experience the first outward signs of aging. Wrinkles begin to appear, joints ache after a highly active day, and body fat accumulates. There is also a loss of muscle tone and elasticity in the connective tissue.[2] Many people in their late thirties and in their forties notice a decline in endurance, the onset of wear-and-tear injuries (such as osteoarthritis), and changes in the digestive system. Wounds and other injuries also take longer to heal. Body composition changes due to fat deposits in the trunk. To maintain health and wellness during the middle-aged years and beyond, it is important to:

- maintain a healthy body weight
- consume nutrient-dense foods
- drink alcohol moderately or not at all
- be a nonsmoker
- engage in moderate physical activity at least 150 minutes per week

Energy and Macronutrients

The energy requirements for ages thirty-one to fifty are 1,800 to 2,200 calories for women and 2,200 to 3,000 calories for men, depending on activity level. These estimates do not include women who are pregnant or breastfeeding. Middle-aged adults must rely on healthy food sources to meet these needs. In many parts of North America, typical dietary patterns do not match the recommended guidelines. For example, five foods—iceberg lettuce, frozen potatoes, fresh potatoes, potato chips, and canned tomatoes—account for over half of all vegetable intake.[3] Following the dietary guidelines in the middle-aged years provides adequate but not excessive energy, macronutrients, vitamins, and minerals.

The AMDRs for carbohydrates, protein, fat, fiber, and fluids remain the same from young adulthood into middle age. It is important to avoid putting on excess pounds and limiting an intake of saturated fats, added sugars and sodium to help avoid cardiovascular disease, diabetes, and other chronic conditions.

Micronutrients

There are some differences, however, regarding micronutrients. For men, the recommendation for magnesium increases to 420 milligrams daily, while middle-aged women should increase their intake of magnesium to 320 milligrams per day. Other key vitamins needed during the middle-aged years include folate and vitamins B6 and B12 to prevent elevation of homocysteine, a byproduct of metabolism that can damage arterial walls and lead to atherosclerosis, a cardiovascular condition.

For Women Aged 51 and Older

- **Iron:** The Recommended Dietary Allowance (RDA) for iron decreases from 18 mg/day to 8 mg/day, as iron requirements drop after menstruation ends.
- **Calcium:** The RDA for calcium increases from 1,000 mg/day to 1,200 mg/day to help slow bone loss and reduce the risk of osteopenia and osteoporosis, which become more common due to decreased estrogen levels during menopause.

Again, it is important to meet nutrient needs with food first, then supplementation, such as a daily multivitamin, if you can't meet

your needs through food.

Preventive/Defensive Nutrition

During the middle-aged years, preventive nutrition can promote wellness and help organ systems to function optimally throughout aging. Preventive nutrition is defined as dietary practices directed toward reducing disease and promoting health and well-being. Healthy eating in general—such as eating unrefined carbohydrates instead of refined carbohydrates and avoiding trans fats and saturated fats—helps to promote wellness. However, there are also some things that people can do to target specific concerns. One example is consuming foods high in antioxidants, such as strawberries, blueberries, and other colorful fruits and vegetables, to reduce the risk of cancer.

Phytochemicals are also great nonessential nutrients that may promote body wellness.For example, carotenoids, which are found in carrots, cantaloupes, sweet potatoes, and butternut squash, may protect against cardiovascular disease by helping to prevent the oxidation of cholesterol in the arteries, although research is ongoing.[4] According to the American Cancer Society, some studies suggest that a phytochemical found in watermelons and tomatoes called lycopene may protect against stomach, lung, and prostate cancer, although more research is needed.[5]

Omega-3 fatty acids can help to prevent coronary artery disease. These crucial nutrients are found in oily fish, including salmon, mackerel, tuna, herring, cod, and halibut. Other beneficial fats that are vital for healthy functioning include monounsaturated fats, which are found in plant oils, avocados, peanuts, and pecans.

Menopause

In the middle-aged years, women undergo a specific change that has a major effect on their health. They begin the process of menopause, typically in their late forties or early fifties. The ovaries slowly cease to produce estrogen and progesterone, which results in the end of menstruation. Menopausal symptoms can vary, but often include hot flashes, night sweats, and mood changes. The hormonal changes that occur during menopause can lead to a number of physiological changes as well, including alterations in body composition, such as weight gain in the abdominal area. Bone loss is another common condition related to menopause due to the loss of female reproductive hormones. Bone thinning increases the risk of fractures, which can affect mobility and the ability to complete everyday tasks, such as cooking, bathing, and dressing.[6]

Recommendations for women experiencing menopause or perimenopause (the stage just prior to the end of the menstruation) include:

- consuming a variety of whole grains, and other nutrient-dense foods
- maintaining a diet high in fiber, low in fat, and low in sodium
- avoiding caffeine, spicy foods, and alcohol to help prevent hot flashes
- eating foods rich in calcium, or taking physician-prescribed calcium supplements and vitamin D
- doing stretching exercises to improve balance and flexibility and reduce the risk of falls and fractures

Query 13.2.3.1

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13.2.4: Nutrition in Older Adults

The senior years are the period from age 65 y until the end of life. A number of physiological and emotional changes take place during this life stage, and as they age, older adults can face a variety of health challenges. Blood pressure rises, and the immune system may have more difficulty battling invaders and infections. The skin becomes thinner and more wrinkled and may take longer to heal after injury. Older adults may gradually lose an inch or two in height. And short-term memory might not be as keen as it once was. However, many older adults remain in relatively good health and continue to be active into their golden years. Good nutrition is important to maintaining health later in life. In addition, the fitness and nutritional choices made earlier in life set the stage for continued health and happiness.

As noted earlier in this textbook, Dietary Reference Intakes (DRIs) vary based on age. Beginning at age 51 (and at age 71 for males for some nutrients), nutrient requirements for adults change in order to fit the nutritional issues and health challenges that older people face. Because the process of aging affects nutrient needs, some requirements for nutrients decrease as a person ages, while requirements for other nutrients increase. On this page, we will take a look at the changing nutrient requirements for older adults as well as some special concerns for the aging population.



Nutrient Needs in Older Adults

Energy and Macronutrients

Due to reductions in lean body mass and metabolic rate, older adults have lower calorie needs than younger adults. The energy requirements for people ages 51 and older are 1,600 to 2,200 calories for women and 2,000 to 2,800 calories for men, depending on activity level. The decrease in physical activity that is typical of older adults also influences nutrition requirements. The AMDRs for carbohydrates, protein, and fat remain the same from middle age into old age. Older adults should substitute more unrefined carbohydrates, such as whole grains, for refined ones. Fiber is especially important in preventing constipation and diverticulitis, which is more common as people age, and it may also reduce the risk of colon cancer. Protein should be lean, and healthy fats, such as omega-3 fatty acids, are a part of any good diet.

Micronutrients

The recommended intake levels of several micronutrients are increased in older adulthood, while others are decreased. A few nutrient changes to note include the following:

- To slow bone loss, the recommendations for **calcium** increase from 1,000 milligrams per day to 1,200 milligrams per day for

both men and women.
- Also to help protect bones, **vitamin D** recommendations increase from 600 IU to 800 IU per day for men and women.
- **Vitamin B_6** recommendations rise to 1.7 milligrams per day for older men and 1.5 milligrams per day for older women to help lower levels of homocysteine and protect against cardiovascular disease.
- Due to a decrease in the production of stomach acid, which can lead to an overgrowth of bacteria in the small intestine and decrease absorption of **vitaminB_{12}**, older adults need an additional 2.4 micrograms per day of B_{12} compared to younger adults.
- For older adult women, higher **iron** levels are no longer needed post-menopause, and recommendations decrease from 18 milligrams per day to 8 milligrams per day.

Common Health Concerns in Older Adults

Older adults may face serious health challenges in their later years, many of which have ties to nutrition.

- Increased occurrence of cancer, heart disease, and diabetes
- Loss of hormone production, bone density, muscle mass, and strength, as well as changes in body composition (increase of fat deposits in the abdominal area, increasing the risk for type 2 diabetes and cardiovascular disease)
- Increased occurrence of dementia, resulting in memory loss, agitation and delusions
- Decreased kidney function, becoming less effective in excreting metabolic products such as sodium, acid, and potassium, which can alter water balance and hydration status
- Decreased immune function, resulting in more susceptibility to illness
- Increased risk for neurological disorders and psychological conditions (e.g., depression), influencing attitudes toward food, along with the ability to prepare or ingest food
- Dental problems can lead to difficulties with chewing and swallowing, which in turn can make it hard to maintain a healthy diet
- Lower efficiency in the absorption of vitamins and minerals
- Being either underweight or overweight



Nutrition Concerns for Older Adults

Dietary choices can help improve health during this life stage and address some of the nutritional concerns that many older adults face. In addition, there are specific concerns related to nutrition that affect adults in their later years. They include medical problems, such as disability and disease, which can impact diet and activity level.

Socioeconomic Challenges and Their Impact on Nutrition and Mental Health in Older Adults

As adults age, socioeconomic challenges such as poverty and food insecurity can significantly impact their overall health and nutritional status. Limited financial resources may restrict access to nutritious foods, leading to poor dietary intake and

heightened risk for chronic conditions like heart disease, diabetes, and malnutrition. In addition, many older adults experience social isolation — whether due to mobility limitations, loss of loved ones, or reduced community engagement — which has been strongly linked to declining mental health, including depression and cognitive decline. These interconnected issues can create a cycle in which inadequate nutrition and emotional distress exacerbate one another, further compromising health outcomes. Addressing food access, enhancing community support, and integrating mental health care into services for older adults are essential strategies for promoting healthy aging.

Sensory Issues

At about age 60, taste buds begin to decrease in size and number. As a result, the taste threshold is higher in older adults, meaning that more of the same flavor must be present to detect the taste. Many older adults lose the ability to distinguish between salty, sour, sweet, and bitter flavors. This can make food seem less appealing and decrease appetite. Intake of foods high in sugar and sodium can increase due to an inability to discern those tastes. The sense of smell also decreases, which impacts attitudes toward food. Sensory issues may also affect digestion, because the taste and smell of food stimulates the secretion of digestive enzymes in the mouth, stomach, and pancreas.

Dysphagia

Some older adults have difficulty getting adequate nutrition because of the disorder ***dysphagia***, which impairs the ability to swallow. Stroke, which can damage the parts of the brain that control swallowing, is a common cause of dysphagia. Dysphagia is also associated with advanced dementia because of overall brain function impairment. To assist older adults suffering from dysphagia, it can be helpful to alter food consistency. For example, solid foods can be pureed, ground, or chopped to allow more successful and safe swallowing. This decreases the risk of ***aspiration***, which occurs when food flows into the respiratory tract and can result in pneumonia. Typically, speech therapists, physicians, and dietitians work together to determine the appropriate diet for dysphagia patients.

Obesity in Old Age

Similar to other life stages, obesity is a concern for older adults. Adults over age 60 are more likely to be obese than young or middle-aged adults. Reduced muscle mass and physical activity mean that older adults need fewer calories per day to maintain a normal weight. Being overweight or obese increases the risk for potentially fatal conditions that can afflict older adults, particularly cardiovascular disease and type 2 diabetes. Obesity is also a contributing factor for 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 older adults can be beneficial, it is best to be cautious and consult with a healthcare professional before beginning a weight loss program.

The Anorexia of Aging

In addition to concerns about obesity among 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 older adults leads to a higher risk for immune deficiency, frequent falls, muscle loss, and cognitive deficits. It is important for health care providers to examine the causes for anorexia of aging, which can vary from one individual to another. Understanding why some older adults eat less as they age can help healthcare professionals assess the risk factors associated with this condition. Decreased intake may be due to disability or the lack of a motivation to eat. Also, many older adults skip at least one meal each day. As a result, some older adults are unable to meet even reduced energy needs.

Nutrition interventions for anorexia of aging should focus primarily on a healthy diet. Remedies can include increasing the frequency and variety of meals and adding healthy, high-calorie foods (such as nuts, potatoes, whole-grain pasta, and avocados) to the diet. The use of flavor enhancements with meals and oral nutrition supplements between meals may help to improve caloric intake.[1] Health care professionals should consider a patient's habits and preferences when developing a nutrition treatment plan. After a plan is in place, patients should be weighed on a weekly basis until they show improvement.

Vision Problems

Many older people suffer from vision loss and other vision problems. Age-related macular degeneration is the leading cause of blindness in Americans over age sixty.[2] This disorder can make food planning and preparation extremely difficult, and people who suffer from it often depend on caregivers for their meals. Self-feeding also may be difficult if an older adult cannot see their food clearly. Friends and family members can help older adults with shopping and cooking. Food-assistance programs for older adults (such as Meals on Wheels) can also be helpful. Diet may also help to prevent macular degeneration. Consuming colorful fruits and vegetables increases the intake of lutein and zeaxanthin, two antioxidants that provide protection for the eyes.

Alcohol Use Disorder

Alcohol use disorder (AUD) among older adults — especially older women — in the United States has been rising, with serious and often under-recognized harm. A 2025 study by Danpanichkul et al. shows that among U.S. adults over age 70, both the prevalence and mortality from AUD, alcohol-associated liver disease (ALD), and alcohol-attributable primary liver cancer have increased over the past two decades. Older women are particularly vulnerable: though men still tend to drink more and have the higher absolute risk, women are experiencing **faster proportional increases** in alcohol-related deaths. For example, from 1999 to 2020, alcohol-related mortality nearly doubled overall, and deaths among women increased about 2.5 times — far greater relative growth than among men.

In older women, physiological changes with aging — notably reduced water content, slower metabolism of alcohol, changes in liver function — mean that even modest alcohol intake can produce higher blood alcohol levels and more damage. Meanwhile, older adults often have comorbid conditions (cardiovascular disease, diabetes, etc.), take medications that interact with alcohol, or have greater frailty, making alcohol's negative effects (falls, fractures, cognitive decline) more likely.

Recent work has also emphasized that there's **no perfectly safe level** of alcohol, especially for women. A mentioned earlier in this textbook, cancer risk increases even with low levels of drinking, and women have greater risk per drink for alcohol-attributable cancers than men. Taken together, the trend, physiology, and outcomes suggest that for older women, even what was once considered "moderate" drinking carries significant risk.

Given all this, older adults need to pay careful attention to alcohol intake. For older women, and for older adults in general, the safest amount for good health is **zero**. Abstaining eliminates the risks associated with AUD, ALD, injury, cancer, and other harm that increase with any alcohol use. If cutting out alcohol completely isn't feasible, reducing to absolutely minimal levels and avoiding drinking in risky situations (e.g., when taking interacting medications, when balance or cognition are compromised, or when coping with loneliness or depression) is critical — and speaking with a healthcare provider about one's drinking is strongly urged.

Dehydration

As people grow older, their risk of dehydration increases for several physiologic reasons. One key factor is body-composition change: with aging there tends to be increased percentage of body fat and a decline in lean body mass (e.g., muscle, organs) and because lean body tissue is what holds most of the body's water (fat holds very little), total body water stores shrink. Because of that reduced capacity to "store" water, older adults may be less buffered against periods of low fluid intake.

Another contributor is increasingly impaired thirst perception (thirst receptors or related signaling). Studies show that older adults do not feel as thirsty under the same conditions of dehydration (such as after water-deprivation or hyperosmotic challenge) as younger people, nor do they increase fluid intake to the same degree. Their baseline blood osmolarity tends to be higher, so the "set-point" for triggering thirst is shifted; also, the speed and magnitude of drinking responses are reduced.

These two changes — less water stored in the body, and less reliable internal signaling to drink — combine to make dehydration more likely, even when older adults are consuming what "feels" like a normal amount of fluid. Dehydration in older people is associated with fatigue, impaired cognition, increased risk of falls, urinary tract infections, kidney problems, and worse aging-related outcomes.

Suggestions for staying well-hydrated, even if not feeling thirsty:

- Establish a routine: drink fluids at set times (e.g., with each meal, mid-morning, mid-afternoon) rather than waiting for thirst.
- Keep water or other preferred fluids easily accessible — for example: by the bedside or carry a water bottle
- Include hydrating foods: fruits and vegetables with high water content (e.g., watermelon, cucumbers, oranges) help provide fluids.
- Use reminders: phone alarms, sticky notes, caregiving prompts.
- Prefer drinks that are palatable: flavored water, herbal teas, or mild, lightly sweetened options if needed, to encourage intake.
- Monitor factors that increase fluid loss: hot weather, exercise, medications (e.g., diuretics), illness with fever or vomiting/diarrhea — increase intake accordingly.
- When fluid retention of electrolytes is relevant (e.g., after sweating, with illness), include mild electrolyte drinks or foods to help maintain balance.
- For those in care settings or with mobility issues, ensure staff/caregivers offer fluids frequently and assist if needed.

Food Safety

Adults aged 65 and older are more likely to be hospitalized or die from foodborne illness. This increased risk of foodborne illness is because organs and body systems go through changes as people age:

- The body's immune response to disease grows weaker.
- The gastrointestinal tract holds onto food for a longer period of time, allowing bacteria to grow.
- The liver and kidneys may not properly rid the body of foreign bacteria and toxins.
- The stomach may not produce enough acid. The acidity helps to reduce the number of bacteria in our intestinal tract.
- Underlying chronic conditions, such as diabetes and cancer, may also increase a person's risk of foodborne illness.

As people age, physiological changes can increase their vulnerability to foodborne illnesses. Mentioned in one of the bullets above is the natural decline in stomach acid production (hypochlorhydria), which compromises the stomach's ability to kill harmful pathogens such as Salmonella, E. coli, and Listeria monocytogenes. Additionally, age-related weakening of the immune system — termed immunosenescence — further reduces the body's ability to fight infections. Chronic diseases common among older adults (e.g., diabetes, kidney disease, or cancer) and medications that suppress immune response can compound these risks. As a result, older adults are more likely to experience severe complications from foodborne illness, including hospitalization or death. Safe food handling, storage, and preparation practices are especially essential to protect this population from preventable health threats.

Table: Food Safety Do's and Don'ts for Older Adults

Do	Don't
Cook meat, poultry, and seafood to safe internal temperatures (e.g., 165°F/74°C for poultry).	Don't eat undercooked or raw meat, poultry, seafood, or eggs.
Reheat leftovers to at least 165°F (74°C) and ensure even heating.	Don't eat leftovers that are more than 3–4 days old.
Wash hands, utensils, and surfaces before and after handling food.	Don't cross-contaminate raw and cooked foods using the same surfaces.
Store refrigerated foods at or below 40°F (4°C) and use them promptly.	Don't leave perishable food out at room temperature for more than 2 hours.
Choose pasteurized dairy products and juices.	Don't consume unpasteurized milk, cheese, or juice.

Do	Don't
Check food expiration dates and inspect packaging for damage.	Don’t eat foods past their expiration date or from bulging cans.
When in doubt, throw it out — better safe than sorry.	Don’t taste food to determine if it’s still safe.

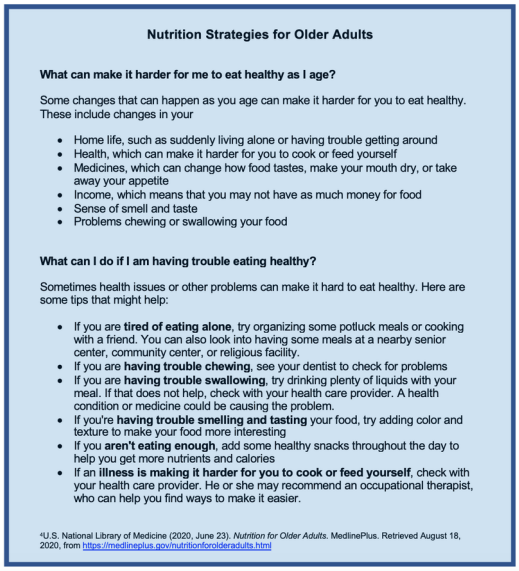


Figure 13.2.4.1: A poster available from FoodSafety.gov with helpful tips and info on food safety for older adults.

Longevity and Nutrition

Bad habits and poor nutrition have an accrual effect. The foods you consume in your younger years will impact your health as you age, from childhood into the later stages of life. As a result, good nutrition today means optimal health tomorrow. Therefore, it is best to start making healthy choices from a young age and maintain them as you mature. However, research suggests that adopting good nutritional choices later in life, during the 40s, 50s, and even the 60s, may still help to reduce the risk of chronic disease as you grow older.[3]

Even if past nutrition and lifestyle choices were not aligned with dietary guidelines, older adults can still do a great deal to reduce their risk of disability and chronic disease. There are a number of changes middle-aged adults can implement, even after years of unhealthy choices. Choices include eating more dark, green, leafy vegetables, choosing lean sources of protein such as lean meats, poultry, fish, beans, and nuts, and engaging in moderate physical activity for at least thirty minutes per day, several days per week. The resulting improvements will go a long way toward providing greater protection against falls and fractures, and helping to ward off cardiovascular disease and hypertension, among other chronic conditions.[3]



Nutrition Strategies for Older Adults

What can make it harder for me to eat healthy as I age?

Some changes that can happen as you age can make it harder for you to eat healthy. These include changes in your

- Home life, such as suddenly living alone or having trouble getting around
- Health, which can make it harder for you to cook or feed yourself
- Medicines, which can change how food tastes, make your mouth dry, or take away your appetite
- Income, which means that you may not have as much money for food
- Sense of smell and taste
- Problems chewing or swallowing your food

What can I do if I am having trouble eating healthy?

Sometimes health issues or other problems can make it hard to eat healthy. Here are some tips that might help:

- If you are **tired of eating alone**, try organizing some potluck meals or cooking with a friend. You can also look into having some meals at a nearby senior center, community center, or religious facility.
- If you are **having trouble chewing**, see your dentist to check for problems
- If you are **having trouble swallowing**, try drinking plenty of liquids with your meal. If that does not help, check with your health care provider. A health condition or medicine could be causing the problem.
- If you're **having trouble smelling and tasting** your food, try adding color and texture to make your food more interesting
- If you **aren't eating enough**, add some healthy snacks throughout the day to help you get more nutrients and calories
- If an **illness is making it harder for you to cook or feed yourself**, check with your health care provider. He or she may recommend an occupational therapist, who can help you find ways to make it easier.

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Figure 11.7. Nutrition strategies for older adults

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CHAPTER 14: FOOD SAFETY

Learning Objectives

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

- Describe the major types and causes of and contamination
- Describe the purpose and process of food irradiation
- Describe consumer-level techniques for avoiding foodborne illness

14.1: Introduction to Food Safety

14.2: The Major Types of Foodborne Illness

14.3: The Causes of Food Contamination

14.4: Protecting the Public Health

14.5: The Food System

14.6: Food Preservation

14.7: Food Processing

14.8: The Effect of New Technologies

14.9: Efforts on the Consumer Level — What You Can Do

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14.1: Introduction to Food Safety

Ka lepo ke kumu wai, e hua‘i ana ka lepo kai

When the source of water is dirty, the dirt is carried to the sea.



Figure 14.1.1: Image by Maarten Van de Heuvel on unsplash.com / CCO

Foodborne Illness and Food Safety

Foodborne illness is a serious threat to health. Sometimes called “food poisoning,” foodborne illness is a common public health problem that can result from exposure to a pathogen or a toxin via food or beverages. Raw foods, such as seafood, produce, and meats, can all be contaminated during harvest (or slaughter for meats), processing, packaging, or during distribution, though meat and poultry are the most common source of foodborne illness. For all kinds of food, contamination also can occur during preparation and cooking in a home kitchen or in a restaurant. For example in 2009, the Marshall Islands reported 174 cases presenting with vomiting and diarrhea. After an epidemiological investigation was completed, they identified the cause to be egg sandwiches that had been left at room temperature too long resulting in the growth of foodborne toxins in the egg sandwiches.[1]

In many developing nations, contaminated water is also a major source of foodborne illness. Many people are affected by foodborne illness each year, making food safety a very important issue. Annually, one out of six Americans becomes sick after consuming contaminated foods or beverages.[2] Foodborne illness can range from mild stomach upset to severe symptoms, or even fatalities. The problem of food contamination can not only be dangerous to your health, it can also be harmful to your wallet. Medical costs and lost wages due to salmonellosis, just one foodborne disease, are estimated at over $1 billion per year.

At-Risk Groups

No one is immune from consuming contaminated food but, whether you become seriously ill depends on the microorganism, the amount you have consumed, and your overall health. In addition, some groups have a higher risk than others for developing severe complications to foodborne disease. Who is most at risk? Young children, elderly people, and pregnant women all have a higher chance of becoming very sick after consuming contaminated food. Other high-risk groups include people with compromised immune systems due to HIV/AIDS, immunosuppressive medications (such as after an organ transplant), and long-term steroid use for asthma or arthritis. Exposure to contaminated food could also pose problems for diabetics, cancer patients, people who have liver disease, and people who have stomach problems as a result of low stomach acid or previous stomach surgery. People in all of these groups should handle food carefully, make sure that what they eat has been cooked thoroughly, and avoid taking any chances that could lead to exposure.

Learning Activities

Query 14.1.1

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1. Thein CC, Trinidad RM, Pavlin B. (2010). A Large Foodborne Outbreak on a Small Pacific Island. *Pacific Health Dialogue, 16*(1). https://www.ncbi.nlm.nih.gov/pubmed/20968238. Accessed January 28, 2018. ↵
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14.2: The Major Types of Foodborne Illness

Foodborne illnesses are either infectious or toxic in nature. The difference depends on the agent that causes the condition. Microbes, such as bacteria, cause food infections, while toxins, such as the kind produced by molds, cause intoxications. Different diseases manifest in different ways, so signs and symptoms can vary with the source of contamination. However the illness occurs, the microbe or toxin enters the body through the gastrointestinal tract, and as a result common symptoms include diarrhea, nausea, and abdominal pain. Additional symptoms may include vomiting, dehydration, lightheadedness, and rapid heartbeat. More severe complications can include a high fever, diarrhea that lasts more than three days, prolonged vomiting, bloody stools, and signs of shock.

One of the biggest misconceptions about foodborne illness is that it is always triggered by the last meal that a person ate. However, it may take several days or more before the onset of symptoms. If you develop a foodborne illness, you should rest and drink plenty of fluids. Avoid antidiarrheal medications, because they could slow the elimination of the contaminant.

Food Infection

According to the CDC, more than 250 different foodborne diseases have been identified.[1] Majority of these diseases are food infections, which means they are caused from food contaminated by microorganisms, such as bacteria, by microscopic animals called parasites, or by viruses. The infection then grows inside the body and becomes the source of symptoms. Food infections can be sporadic and often are not reported to physicians. However, occasional outbreaks occur that put communities, states and provinces, or even entire nations at risk. For example, in 1994, an outbreak of the infection salmonellosis occurred in the United States due to contaminated ice cream. An estimated 224,000 people became ill. In 1988, contaminated clams resulted in an outbreak of hepatitis A in China, which affected about 300,000 people.[2]

The Reproduction of Microorganisms

Bacteria, one of the most common agents of food infection, are single-celled microorganisms that are too small to be seen with the human eye. Microbes live, die, and reproduce, and like all living creatures, they depend on certain conditions to survive and thrive. In order to reproduce within food, microorganisms require the following:

- Temperature. Between 40°F and 140°F, which is called the danger zone, bacteria grow rapidly.
- Time. More than two hours in the danger zone.
- Water. High moisture content is helpful. Fresh fruits and vegetables have the highest moisture content.
- Oxygen. Most microorganisms need oxygen to grow and multiply, but a few are anaerobic and do not.
- Acidity and pH Level. Foods that have a low level of acidity (or a high pH level) provide an ideal environment, since most microorganisms grow best around pH 7.0 and not many will grow below pH 4.0 . Examples of higher pH foods include egg, meat, seafood, milk, and corn. Examples of low pH foods include citrus fruits, sauerkraut, tomatoes, and pineapples.
- Nutrient Content. Microorganisms need protein, starch, sugars, fats, and other compounds to grow. Typically high-protein foods are better for bacterial growth.

Food Intoxication

Other kinds of foodborne illness are food intoxications, which are caused by natural toxins or harmful chemicals. These and other unspecified agents are major contributors to episodes of acute gastroenteritis and other kinds of foodborne illness.[3] Like pathogens, toxins and chemicals can be introduced to food during cultivation, harvesting, processing, or distribution. Some toxins can lead to symptoms that are also common to food infection, such as abdominal cramping, while others can cause different kinds of symptoms and complications, some very severe. For example, mercury, which is sometimes found in fish, can cause neurological damage in infants and children. Exposure to cadmium can cause kidney damage, typically in elderly people.

Learning Activities

Query 14.2.1

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1. Foodborne Illnesses and Germs. (2018). Centers for Disease Control and Prevention.https://www.cdc.gov/foodsafety/foodborne-germs.html . Updated January 23, 2018. Accessed January 28, 2017. ↵
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14.3: The Causes of Food Contamination

Both food infections and food intoxications can create a burden on health systems, when patients require treatment and support, and on food systems, when companies must recall contaminated food or address public concerns. It all begins with the agent that causes the contamination. When a person ingests a food contaminant, it travels to the stomach and intestines. There, it can interfere with the body's functions and make you sick. In the next part, we will focus on different types of food contaminants and examine common microbes, toxins, chemicals, and other substances that can cause food infections and intoxications. Let's begin with pathogens, which include bacteria and viruses. About one hundred years ago, typhoid fever, tuberculosis, and cholera were common diseases caused by food and water contaminated by pathogens. Over time, improvements in food processing and water treatment eliminated most of those problems in North America. Today, other bacteria and viruses have become common causes of food infection.

Bacteria

All foods naturally contain small amounts of bacteria. However, poor handling and preparation of food, along with improper cooking or storage can multiply bacteria and cause illness. In addition, bacteria can multiply quickly when cooked food is left out at room temperature for more than a few hours. Most bacteria grow undetected because they do not change the color or texture of food or produce a bad odor. Freezing and refrigeration slow or stop the growth of bacteria, but does not destroy the bacteria completely. The microbes can reactivate when the food is taken out and thawed.

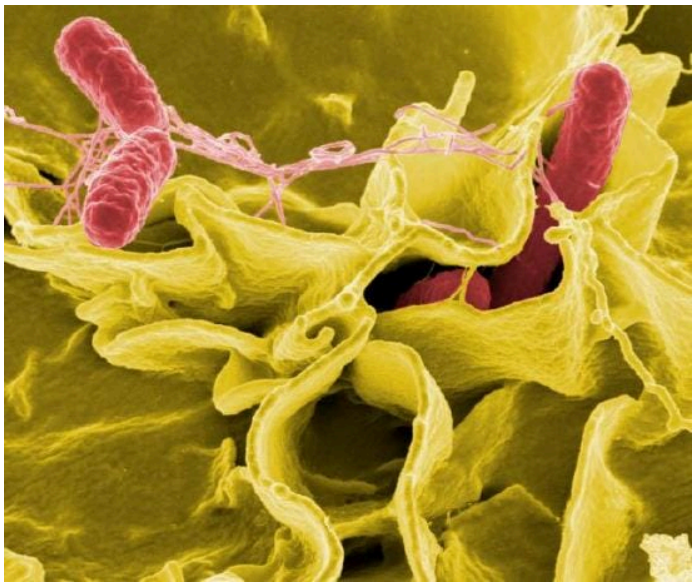


Figure 14.3.1: Image by NIH NIAID / CC BY 2.0

Many different kinds of bacteria can lead to food infections. One of the most common is Salmonella, which is found in the intestines of birds, reptiles, and mammals. Salmonella can spread to humans via a variety of different animal-origin foods, including meats, poultry, eggs, dairy products, and seafood. The disease it causes, salmonellosis, typically brings about fever, diarrhea, and abdominal cramps within twelve to seventy-two hours after eating. Usually, the illness lasts four to seven days, and most people recover without treatment. However, in individuals with weakened immune systems, Salmonella can invade the bloodstream and lead to life-threatening complications, such as a high fever and severe diarrhea.[1]

The bacterium Listeria monocytogenes is found in soft cheeses, unpasteurized milk, meat, and seafood. It causes a disease called listeriosis that can bring about fever, headache, nausea, and vomiting. Listeria monocytogenes mostly affects pregnant women, newborns, older adults, and people with cancer and compromised immune systems.

The food infection by Escherichia coli is found in raw or undercooked meat, raw vegetables, unpasteurized milk, minimally processed ciders and juices, and contaminated drinking water. Symptoms can occur a few days after eating, and include watery and bloody diarrhea, severe stomach cramps, and dehydration. More severe complications may include colitis, neurological

symptoms, stroke, and hemolytic uremic syndrome. In young children, an E. coli infection can cause kidney failure and death.

The bacterium Clostridium botulinum causes botulism. Sources include improperly canned foods, lunch meats, and garlic. An infected person may experience symptoms within four to thirty-six hours after eating. Symptoms could include nerve dysfunction, such as double vision, inability to swallow, speech difficulty, and progressive paralysis of the respiratory system. Botulism can also be fatal.

Campylobacter jejuni causes the disease campylobacteriosis. It is the most commonly identified bacterial cause of diarrhea worldwide. Consuming undercooked chicken, or food contaminated with the juices of raw chicken, is the most frequent source of this infection. Other sources include raw meat and unpasteurized milk. Within two to five days after consumption, symptoms can begin and include diarrhea, stomach cramps, fever, and bloody stools. The duration of this disease is about seven to ten days.

The food infection shigellosis is caused by Shigella, of which there are several types. Sources include undercooked liquid or moist food that has been handled by an infected person. The onset of symptoms occurs one to seven days after eating, and can include stomach cramps, diarrhea, fever, and vomiting. Another common symptom is blood, pus, or mucus in stool. Once a person has had shigellosis, the individual is not likely to get infected with that specific type again for at least several years. However, they can still become infected with other types of Shigella.

Staphylococcus aureus causes staphylococcal food poisoning. Food workers who carry this kind of bacteria and handle food without washing their hands can cause contamination. Other sources include meat and poultry, egg products, cream-filled pastries, tuna, potato and macaroni salad, and foods left unrefrigerated for long periods of time. Symptoms can begin thirty minutes to eight hours after eating, and include diarrhea, vomiting, nausea, stomach pain, and cramps. This food infection usually lasts one to two days.

Found in raw oysters and other kinds of seafood, Vibrio vulnificus belongs to the same family as the bacteria which cause cholera. This food contaminant can result in the Vibrio infection. Symptoms can begin anywhere from six hours to a few days after consumption, and include chills, fever, nausea, and vomiting. This disease is very dangerous and can result in fatalities, especially in people with underlying health problems.[2]

Virus

Viruses are another type of pathogen that can lead to food infections, however they are less predominant than bacteria. Viruses differ from bacteria in that they cannot grow and reproduce in foods. Instead, viruses that cause human diseases can only reproduce inside human cells (Figure 14.3.2). Hepatitis A is one of the more well-known food-contaminating viruses. Sources include raw shellfish from polluted water, and food handled by an infected person. This virus can go undetected for weeks and, on average, symptoms do not appear until about one month after exposure. At first, symptoms include malaise, loss of appetite, nausea, vomiting, and fever. Three to ten days later, additional symptoms can manifest, including jaundice and darkened urine. Severe cases of a hepatitis A can result in liver damage and death.

The most common form of contamination from handled foods is the norovirus, which is also known as the Norwalk-like virus, or the calicivirus. Sources include raw shellfish from polluted water, salads, sandwiches, and other ready-to-eat foods handled by an infected person. The norovirus causes gastroenteritis and within one to three days it leads to symptoms, such as nausea, vomiting, diarrhea, stomach pain, headache, and a low-grade fever.[3]

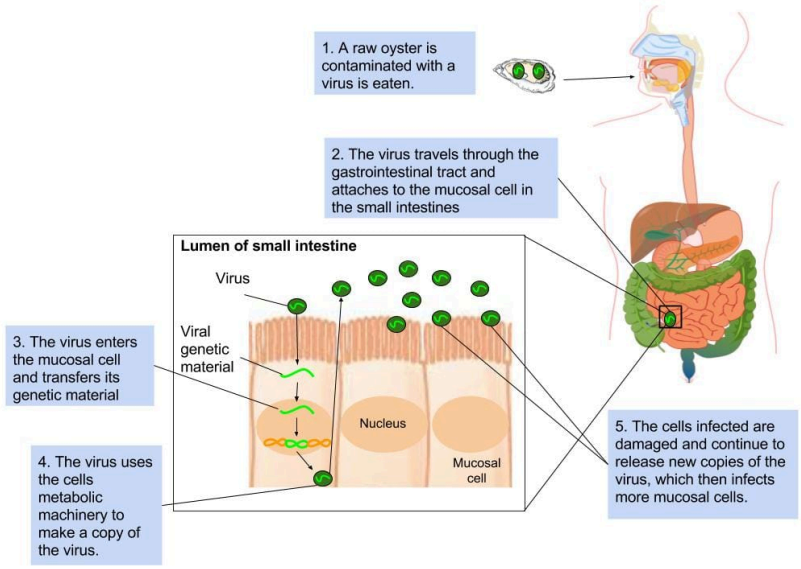


Figure 14.3.2: Viruses in the Human Body. Image by Allison Calabrese / CC BY 4.0

Parasitic Protozoa

Food-contaminating parasitic protozoa are microscopic organisms that may be spread in food and water. Several of these creatures pose major problems to food production worldwide. They include Anisakis, microscopic worms that invade the stomach or the intestines. Sources of this parasite include raw fish. This parasite can result in the Anisakis infection, with symptoms that begin within a day or less and include abdominal pain, which can be severe.

Cryptosporidium lives in the intestines of infected animals. Another common source is drinking water, when heavy rains wash animal wastes into reservoirs. One major problem with this pathogen is that it is extremely resistant to disinfection with chlorine. Cryptosporidium causes the disease cryptosporidiosis, with symptoms that begin one to twelve days after exposure and include watery stools, loss of appetite, vomiting, a low-grade fever, abdominal cramps, and diarrhea. For HIV/AIDS patients and others with weakened immune systems, the disease can be severe, and sometimes can lead to death.

Giardia lamblia is another parasite that is found in contaminated drinking water. In addition, it lives in the intestinal tracts of animals, and can wash into surface water and reservoirs, similar to Cryptosporidium. Giardia causes giardiasis, with symptoms that include abdominal cramping and diarrhea within one to three days. Although most people recover within one to two weeks, the disease can lead to a chronic condition, especially in people with compromised immune systems.

The parasite Toxoplasma gondii causes the infection toxoplasmosis, which is a leading cause of death attributed to foodborne illness in the United States. More than sixty million Americans carry Toxoplasma gondii, but very few have symptoms. Typically, the body's immune system keeps the parasite from causing disease. Sources include raw or undercooked meat and unwashed fruits and vegetables. Handling the feces of a cat with an acute infection can also lead to the disease.[4]

Mold Toxins

Mold can grow on fruits, vegetables, grains, meats, poultry, and dairy products, and typically appears as gray or green "fur."



Figure 14.3.3: Moldy nectarines by Roger McLassus 1951 / CC BY-SA 3.0

Warm, humid, or damp conditions encourage mold to grow on food. Molds are microscopic fungi that live on animals and plants. No one knows how many species of fungi exist, but estimates range from ten- to three-hundred thousand. Unlike single-celled bacteria, molds are multicellular, and under a microscope look like slender mushrooms. They have stalks with spores that form at the ends. The spores give molds their color and can be transported by air, water, or insects. Spores also enable mold to reproduce. Additionally, molds have root-like threads that may grow deep into food and be difficult to see. The threads are very deep when a food shows heavy mold growth. Foods that contain mold may also have bacteria growing alongside it.

Some molds, like the kind found in blue cheese, are desirable in foods, while other molds can be dangerous. The spores of some molds can cause allergic reactions and respiratory problems. In the right conditions, a few molds produce mycotoxins, which are natural, poisonous substances that can make you sick if they are consumed. Mycotoxins are contained in and around mold threads, and in some cases, may have spread throughout the food. The Food and Agriculture Organization of the United Nations estimates that mycotoxins affect 25 percent of the world's food crops. They are found primarily in grains and nuts, but other sources include apples, celery, and other produce.

The most dangerous mycotoxins are aflatoxins, which are produced by strains of fungi called Aspergillus under certain temperature and humidity conditions. Contamination has occurred in peanuts, tree nuts, and corn. Aflatoxins can cause aflatoxicosis in humans, livestock, and domestic animals. Symptoms include vomiting and abdominal pain. Possible complications include liver failure, liver cancer, and even death. Many countries try to limit exposure to aflatoxins by monitoring their presence on food and feed products.[5]

Poisonous Mushrooms

Like molds, mushrooms are fungi and the poisonous kind produces mycotoxins that can cause food intoxication. Toxic mushrooms, also known as toadstools, can cause severe vomiting and other symptoms. However, only a few varieties are fatal. Toxic mushrooms cannot be made safe by cooking, freezing, canning, or processing. The only way to avoid food intoxication is to refrain from eating them. Mushroom guides can help wild gatherers distinguish between the edible and toxic kinds[6].



Figure 14.3.4: Amanita Muscaria by Onder Wijsgek / CC BY 3.0

Pesticides

Pesticides are important in food production to control diseases, insects, and other pests. They protect crops and ensure a large yield. However, synthetic pesticides can leave behind residues, particularly on produce, that can be harmful to human health. Foods that contain the highest levels of pesticide residue include conventionally-grown peaches, apples, bell peppers, celery, nectarines, strawberries, cherries, pears, spinach, lettuce, and potatoes. Foods that contain the lowest levels of pesticide residue include avocados, pineapples, bananas, mangoes, asparagus, cabbage, and broccoli.[7] In many cases, the amount of pesticide exposure is too small to pose a risk. However, harmful exposures can lead to certain health problems and complications, including cancer. Also, infants and young children are more susceptible to the hazards of pesticides than adults. In addition, using synthetic pesticides, herbicides, and fertilizers contributes to soil and water pollution and can be hazardous to farm workers.

To protect the public and their workers, many farmers now rely on alternatives to synthetic pesticide use, including crop rotation, natural pesticides, and planting non food crops nearby to lure pests away. Some consumers choose to reduce their exposure to pesticides by purchasing organic produce. Organic foods are grown or produced without synthetic pesticides or fertilizer, and all growers and processors must be certified by the US Department of Agriculture (USDA). However, conventionally-grown produce should be fine for fruits and vegetables that appear on the low-residue list.

Pollutants

Pollutants are another kind of chemical contaminant that can make food harmful. Chemical runoff from factories can pollute food products and drinking water. For example, dioxins are chemical compounds created in industrial processes, such as manufacturing and bleaching pulp and paper. Fish that swim in dioxin-polluted waters can contain significant amounts of this pollutant, which causes cancer. When metals contaminate food, it can result in serious and even life-threatening health problems. A common metal contaminant is lead, which can be present in drinking water, soil, and air. Lead exposure most often affects children, who can suffer from physical and mental developmental delays as a result.

Methyl mercury occurs naturally in the environment and is also produced by human activities. Fish can absorb it, and the predatory fish that consume smaller, contaminated fish can have very high levels. This highly toxic chemical can cause mercury poisoning, which leads to developmental problems in children, as well as autoimmune effects. A condition called Minamata disease was identified in 1956 in Japan. It was named for the town of Minamata, which was the site of an environmental disaster when methyl mercury was released into the surface water near a factory. Many residents experienced neurological issues, including numbness in hands and feet, muscle weakness, a narrowing of the field of vision, damage to hearing and speech, and ataxia, which is a lack of muscle coordination.[8]

PCBs, or polychlorinated biphenyls, are man-made organic compounds that consists of carbon, hydrogen and chlorine. Due to their non-flammability, chemically stable, and high boiling points PCBs were manufactured and used commercially from 1929 until 1979 when it was banned. Like methylmercury, higher concentrations of this contaminant are found in predatory fish. Health effects include complications in physical and neurological development in children, and this compound is potentially a carcinogen. PCB contamination also can affect the immune, reproductive, nervous, and endocrine systems.[9]

Learning Activities

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Query 14.3.2

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14.4: Protecting the Public Health

Most foodborne infections go unreported and undiagnosed. However, the CDC estimates that about seventy-six million people in the United States become ill from foodborne pathogens or other agents every year. In North America, a number of government agencies work to educate the public about food infections and intoxications, prevent the spread of disease, and quell any major problems or outbreaks. They include the CDC, the FDA, and the USDA, among other organizations.

Efforts on the Governmental Level

A number of government agencies work to ensure food safety and to protect the public from foodborne illness. Food regulatory agencies work to protect the consumer and ensure the safety of our food. Food and drug regulation in the United States began in the late nineteenth century when state and local governments began to enact regulatory policies. In 1906, Congress passed the Pure Food and Drugs Act, which led to the creation of the US Food and Drug Administration (FDA). Today, a number of agencies are in charge of monitoring how food is produced, processed, and packaged.[1]

The USDA and the FDA enforce laws regarding the safety of domestic and imported food. In addition, the Federal Food, Drug, and Cosmetic Act of 1938 gives the FDA authority over food ingredients. The FDA enforces the safety of domestic and imported foods. It also monitors supplements, food labels, claims that corporations make about the benefits of products, and pharmaceutical drugs. Sometimes, the FDA must recall contaminated foods and remove them from the market to protect public health. For example, in 2011 contaminated peanut butter led to the recall of thousands of jars of a few popular brands.[2] Recalls are almost always voluntary and often are requested by companies after a problem has been discovered. In rare cases, the FDA will request a recall. But no matter what triggers the removal of a product, the FDA's role is to oversee the strategy and assess the adequacy and effectiveness of the recall.

Many consumers have concerns about safety practices during the production and distribution of food. This is especially critical given recent outbreaks of foodborne illnesses. For example, during fall 2011 in the United States, there was an eruption of the bacteria Listeria monocytogenes in cantaloupe. It was one of the deadliest outbreaks in over a decade and resulted in a number of deaths and hospitalizations.[3] In January 2011, the Food Safety Modernization Act was passed to grant more authority to the FDA to improve food safety. The FDA and other agencies also address consumer-related concerns about protecting the nation's food supply in the event of a terrorist attack.

The USDA headed by the Secretary of Agriculture, develops and executes federal policy on farming and food. This agency supports farmers and ranchers, protects natural resources, promotes trade, and seeks to end hunger in the United States and abroad. The USDA also assures food safety, and in particular oversees the regulation of meat, poultry, and processed egg products. The CDC tracks outbreaks, identifies the causes of food infection and intoxication, and recommends ways to prevent foodborne illness. Other government agencies that play a role in protecting the public include the Food Safety and Inspection Service, a division of the USDA, which enforces laws regulating meat and poultry safety. The Agricultural Research Service, which is the research arm of the USDA, investigates a number of agricultural practices, including those related to animal and crop safety. The National Institute of Food and Agriculture conducts research and education programs on food safety for farmers and consumers.

The Environmental Protection Agency (EPA) works to protect human health and the environment. Founded in 1970, the agency conducts environmental assessment, education, research, and regulation. The EPA also works to prevent pollution and protect natural resources. Two of its many regulatory practices in the area of agriculture include overseeing water quality and the use of pesticides.The EPA approves pesticides and other chemicals used in agriculture, and sets limits on how much residue can remain on food. The FDA analyzes food for surface residue and waxes. Processing methods can either reduce or concentrate pesticide residue in foods. Therefore, the Food Quality Protection Act, which was passed in 1996, requires manufacturers to show that pesticide levels are safe for children.

YouTube Video

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Video 14.4.1: The Trouble with Chicken — PBS Frontline, May 12, 2015. FRONTLINE investigates the spread of dangerous pathogens in our meat — particularly poultry — and why the food-safety system isn't stopping the threat. Focusing on an outbreak of *Salmonella Heidelberg* at one of the nation's largest poultry processors, the documentary reveals how contaminants are evading regulators and causing more severe illnesses at a time when Americans are consuming more chicken than ever. Available at https://www.pbs.org/wgbh/frontline/documentary/trouble-with-chicken/

Recent Developments (2025)

Since President Trump assumed office in 2025, several policy changes at the USDA and EPA have significantly affected the regulatory landscape surrounding food safety and public health. At the USDA, two long-standing scientific advisory committees — the National Advisory Committee on Microbiological Criteria for Foods and the National Advisory Committee on Meat and Poultry Inspection — were quietly eliminated in early 2025, raising concerns about the agency's ability to incorporate independent scientific guidance into regulatory decisions. Around the same time, USDA withdrew a proposed rule that would have established enforceable limits on *Salmonella* contamination in raw poultry, a move that some public health advocates argue weakens efforts to prevent foodborne illness. Even though the agency has announced increased investments in testing, including expanded *Listeria* surveillance and the opening of a new regional laboratory, critics contend these measures do not fully compensate for the rollback of standards and advisory oversight.

At the Environmental Protection Agency (EPA), regulatory shifts have focused on reducing industry compliance burdens, particularly in agriculture and food processing. Notably, in mid-2025 the EPA declined to finalize proposed wastewater discharge limits for meat and poultry processing facilities, citing economic concerns. The agency also advanced a revised pesticide strategy that allows greater flexibility in application practices near protected habitats, while rolling back certain restrictions introduced under earlier administrations.

Perhaps most consequentially, the EPA moved to scale back federal drinking water standards for several per- and polyfluoroalkyl substances (PFAS), delaying enforcement timelines and rescinding some contaminant limits. Given that PFAS can enter the food chain through water, soil, and food packaging, this decision has prompted public health experts to warn of increased long-term exposure risks.

Taken together, these regulatory changes suggest a shift toward a more permissive approach to food and environmental oversight. While some measures may streamline operations or reduce costs for producers, the overall direction raises legitimate questions about the nation's preparedness to prevent, detect, and respond to foodborne illnesses and chemical contaminants in the food supply. The long-term implications for public health will likely depend on how remaining safeguards are implemented and whether future administrations choose to restore more robust oversight mechanisms.

Table: USDA and EPA Changes Since 2025 — Potential Impacts on Food Safety

Agency	Policy/Change	Description	Potential Impact on Food Safety
USDA	Elimination of advisory committees	Disbanded scientific food safety panels	Less independent scientific oversight
USDA	Withdrawal of *Salmonella* rule	Canceled plan to set contamination limits in poultry	Reduced preventive regulation
USDA	Expanded pathogen testing	More *Listeria* testing; new FSIS lab opened	May improve detection; reactive rather than preventive

Agency	Policy/Change	Description	Potential Impact on Food Safety
EPA	PFAS regulation rollback	Scaled back contaminant limits in drinking water	Greater long-term chemical exposure risk
EPA	Revised pesticide strategy	Eased buffer rules; more flexible use near habitats	Increased exposure risk depending on enforcement
EPA	Canceled wastewater rule	Declined stricter discharge limits for processing plants	Potential rise in environmental contaminants

Efforts within the Food Industry

The Hazard Analysis Critical Control Points (HACCP) is a program within the food industry designed to promote food safety and prevent contamination by identifying all areas in food production and retail where contamination could occur. Companies and retailers determine the points during processing, packaging, shipping, or shelving where potential contamination may occur.. Those companies or retailers must then establish critical control points to prevent, control, or eliminate the potential for food contamination. The USDA requires the food industry to follow HACCP for meat and poultry, while the FDA requires it for seafood, low-acid canned-food, and juice. HACCP is voluntary for all other food products but its main goal is to prevent contamination at all costs.

Everyday Connection

The Seven Steps to HACCP:

1. Conduct a hazard analysis: The manufacturer must first determine any food safety hazards (ex. biological, chemicals, or physical) and identify preventative measures to control the hazards.
2. Identify the critical control points: Critical control point (CCP) is a point or procedure in food manufacturing where control can be applied to prevent or eliminate food hazards that may cause the food to be unsafe.
3. Establish critical limits: A critical limit is the maximum or minimum value that a food hazard must be controlled at a CCP to prevent, eliminate or reduce it to an acceptable level.
4. Establish monitoring requirements: The manufacture must establish procedures to monitor the control points to ensure the process is under control and not above the CCP.
5. Establish corrective actions: Corrective actions are needed when monitoring indicates a deviation from the established critical limit to ensure that no produce injurious to health has occurred as a result of the deviation.
6. Establish verification procedures: Verification ensures that the HACCP plan is adequate with CCP records, critical limits and microbial sampling and analysis.
7. Record keeping procedure: The manufacturer must maintain certain documents including its hazard analysis, HACCP plan, and records monitoring the CCP, critical limits, and the verification of handling processed deviations.

For more information on the HACCP visit https://www.fsis.usda.gov/Oa/background/keyhaccp.htm.

Learning Activities

Query 14.4.1

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1. History of Food and Drug Regulation in the United States. (2010). EH.Net Encyclopedia. http://eh.net/?s=History+of+Food+and+Drug+Regulation+in+the+United+States. Published February 4, 2010. Accessed

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14.5: The Food System

The food system is a network of farmers and related operations, including food processing, wholesale and distribution, retail, industry technology, and marketing. The milk industry, for example, includes everything from the farm that raises livestock, to the milking facility that extracts the product, to the processing company that pasteurizes milk and packages it into cartons, to the shipping company that delivers the product to stores, to the markets and groceries that stock and sell the product, to the advertising agency that touts the product to consumers. All of these components play a part in a very large system.

Organic Farming

Organic Farming: Practices, Certification, and Considerations

Organic farming is an agricultural system that emphasizes ecological balance, biodiversity, and soil and water conservation. It avoids the use of most synthetic fertilizers, pesticides, genetically modified organisms (GMOs), irradiation, and sewage sludge. Instead, organic farmers rely on natural substances and physical, mechanical, or biologically based farming methods to the greatest extent possible.

USDA Organic Certification

In the United States, the **U.S. Department of Agriculture (USDA)** regulates the labeling of organic products through its **National Organic Program (NOP)**. To be labeled "USDA Organic," a product must meet strict standards:

- **Land requirements**: No prohibited substances (e.g., synthetic pesticides or fertilizers) used for at least three years prior to harvest.
- **Pest and weed control**: Must use physical, mechanical, or biological methods before resorting to approved organic pesticides.
- **Livestock**: Animals must be fed 100% organic feed, have access to the outdoors, and cannot be given antibiotics or growth hormones.
- **Certification**: Farms and facilities must undergo regular inspections and maintain records to demonstrate compliance.

Only USDA-accredited certifying agents can grant the official **USDA Organic** seal. However, certification is not permanent — farmers must continue to meet requirements to maintain their organic status.

Risks and Requirements

Although organic farming avoids synthetic pesticides, it is not risk-free. Organic-approved pesticides and fertilizers, though often derived from natural sources, can still pose environmental and health risks if misused. Additionally, organic food is **not immune to foodborne illness**. In 2022, an outbreak of **Hepatitis A** in the U.S. was linked to **frozen organic strawberries**, underscoring that organic status does not guarantee safety from viral or bacterial contamination. Proper handling, washing, and food safety practices remain essential.

Consumer Concerns and the EWG "Dirty Dozen"

Some consumers choose organic to reduce exposure to pesticide residues. The **Environmental Working Group (EWG)** publishes an annual list called the **"Dirty Dozen"**, highlighting conventionally grown produce with the highest pesticide residues. In 2025, items like strawberries, spinach, and kale remained at the top of the list.

For those on a budget, choosing organic versions of the "Dirty Dozen" may offer a practical compromise. However, it's important to understand that **pesticide residues on conventional produce are regulated by the EPA and typically fall well below levels considered harmful to humans**.

What Does the Science Say About Pesticide Residues?

Current evidence suggests that **the risk to consumers from pesticide residues in food is very low to minimal**. According to the **U.S. Food and Drug Administration (FDA)** and the **Environmental Protection Agency (EPA)**, the levels found on food are **far below safety thresholds**, even for vulnerable populations such as children and pregnant individuals. Reviews of the scientific literature have not established a consistent link between dietary pesticide exposure and chronic health effects in humans.

A Focus on Agricultural Workers

Although consumer risk may be low, **agricultural pesticide handlers face significantly higher exposure risks**. These individuals — often from vulnerable communities and working under economically and legally precarious conditions — may lack access to **personal protective equipment (PPE)** or appropriate training.

Data from **state-level cholinesterase monitoring programs**, such as those in California and Washington State, have shown measurable suppression of cholinesterase activity in farmworkers exposed to organophosphate pesticides. These enzymes are critical for nervous system function, and their inhibition can lead to acute or chronic neurological effects. Such findings underscore the need for improved protections and regulatory enforcement in the agricultural sector.

Coming Up: Videos for Deeper Insight

To complement this information, the following two videos offer unique perspectives:

1. **A Star Wars Parody — Grocery Store Wars** – A humorous but informative look at the battle between organic and conventional farming methods, dramatized in a galactic showdown.
2. **Conventional vs. Organic Farming — Is Organic Really Better? Healthy Food or Trendy Scam?** – A science-based comparison of the two systems, examining yield, sustainability, labor, and pesticide use through real-world case studies.

YouTube Video

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Video 14.5.1: Grocery Store Wars is a Star Wars parody film created by the Organic Trade Association. The film is meant to promote the purchase of organic foods over unhealthy, chemically processed food. As such, all the characters in the film are portrayed by vegetables and other foodstuffs.. November 14, 2006. Available at https://www.youtube.com/watch?v=hVrIyEu6h_E

YouTube Video

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Video 14.5.1:

Is Organic Really Better? Healthy Food or Trendy Scam?
Organic food is a huge trend: it promises a healthier and better life. But can Organic food really live up to the expectations or is it just baloney? January 13, 2019. Available at https://www.youtube.com/watch?v=8PmM6SUn7Es

Conventional Agriculture

Conventional Farming: Efficiency, Innovation, and the Role of Integrated Pest Management

Conventional farming refers to modern agricultural methods that often rely on **synthetic fertilizers, chemical pesticides, high-yield crop varieties, mechanized equipment**, and, in many cases, **intensive animal production systems**. This system has allowed for massive increases in **global food production**, enabling fewer farmers to feed more people than ever before. However, conventional agriculture is not without its challenges, including concerns around environmental sustainability, soil degradation, pesticide use, and the treatment of animals in large-scale farming operations.

Bridging the Divide: Integrated Pest Management (IPM)

Rather than treating conventional and organic farming as opposing systems, many agricultural scientists advocate for **Integrated Pest Management (IPM)**—a holistic approach that blends the most effective and sustainable elements from both.

IPM emphasizes:

- **Monitoring pest populations** before taking action
- **Targeted pesticide use** only when necessary, using the **least toxic options** first
- Incorporation of **biological controls** (e.g., predatory insects)
- **Crop rotation, cover cropping, and soil health strategies** often associated with organic practices
- The use of **synthetic controls** when warranted, to prevent catastrophic crop losses

The goal of IPM is to **reduce reliance on chemical inputs**, lower production costs, **minimize harm to non-target species**, and support **long-term agricultural sustainability**—all while maintaining or improving yields.

Yield and Land Use: A Global Sustainability Dilemma

With the global population projected to exceed 10 billion by 2050, the question isn't whether we should grow more food — it's **how**.

One critical trade-off in agricultural policy is this:

> **Do we convert more land into farmland (with associated biodiversity loss), or do we maximize yields on the land we already farm?**

Organic farming, while environmentally beneficial in some areas, typically yields **20–25% less** than conventional farming on average. If the world were to switch entirely to organic production without major increases in productivity, significantly more land would be needed to meet current food demands — raising concerns about **deforestation, habitat destruction**, and carbon emissions.

By contrast, conventional farming methods — with their emphasis on **technology, improved seed genetics, and nutrient management** — can produce higher yields per acre. When paired with IPM and other sustainable strategies, conventional systems have the potential to **feed more people with fewer environmental trade-offs**.

Nutrition: Organic vs. Conventional

One of the most frequently asked questions is whether organic food is **more nutritious** than conventionally grown food.

Numerous studies, including a comprehensive review of the literature have concluded that:

- There is **no consistent or significant difference in nutrient content** between organic and conventional produce.
- Some organic produce may contain **slightly higher levels of certain antioxidants**, but the variation is generally small and **unlikely to impact overall health outcomes**.
- The biggest nutritional determinants remain **dietary diversity, food quality, and freshness** — regardless of the production method.

Factory Farms, CAFOs, and Ethical Concerns

Criticism of conventional agriculture often centers on **Concentrated Animal Feeding Operations (CAFOs)**, where large numbers of animals are raised in confined conditions. These operations can contribute to:

- Environmental degradation (e.g., water pollution from manure runoff)
- Public health risks (e.g., antibiotic resistance)
- Animal welfare concerns

However, it is important to note that **organic certification does not always guarantee pasture-raised or small-scale animal farming**. Some **certified organic operations** still function as **large-scale animal production facilities**, albeit with organic feed and without synthetic inputs. These facilities may still raise concerns about animal welfare, transparency, and ecological impact.

Thus, **the line between organic and conventional is not always clear-cut** — particularly in large-scale food production systems.

Moving Forward: Blending Best Practices

Rather than framing agriculture as a binary choice between “natural” and “synthetic,” the future of food likely lies in **integrated approaches** that:

- Use technology and data to **minimize inputs and environmental harm**
- Apply organic principles like **crop diversity and soil stewardship**
- Embrace **precision agriculture** to improve efficiency and reduce waste
- Adopt **animal welfare and sustainability standards** that transcend certification labels

Coming Up: A Glimpse into the Meatrix

To deepen your understanding of the ethical and environmental critiques of large-scale animal farming, watch the following video:

- **A Matrix Parody — The Meatrix** – A humorous yet provocative short film that reimagines factory farming through the lens of *The Matrix*, encouraging viewers to question the systems behind their food choices.

YouTube Video

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Video 14.5.1:
A cartoon parody of the Matrix — Join Leo, the young pig who wonders if he is "the one", Chickity, the feathered family farm defender, and Moopheus, the trench-coat-clad cow with a passion for green pastures as they expose the problems with factory farming while making the world safe for sustainable family farms. June 7, 2011.

Available at https://www.youtube.com/watch?v=u4_pzPrMTrs



Figure 14.5.1: Image by Morten Just / CC BY-NC 3.0

Next, we will cover the important aspects of a food system of preservation and processing. Each provides for or protects consumers in different ways. Food preservation includes the handling or treating of food to prevent or slow down spoilage. Food processing involves transforming raw ingredients into packaged food, from fresh-baked goods to frozen dinners. Although there are numerous benefits to both, preservation and processing also pose some concerns, in terms of both nutrition and sustainability.

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14.6: Food Preservation

Food preservation protects consumers from harmful or toxic food. There are different ways to preserve food. Some are ancient methods that have been practiced for generations, such as curing, smoking, pickling, salting, fermenting, canning, and preserving fruit in the form of jam. Others include the use of modern techniques and technology, including drying, vacuum packing, pasteurization, and freezing and refrigeration. Preservation guards against foodborne illnesses, and also protects the flavor, color, moisture content, or nutritive value of food.

Pasteurization

Pasteurization is a mild heat-treatment process applied to foods in order to reduce the number of viable pathogenic (and many spoilage) microorganisms to levels unlikely to cause disease. The method is named after Louis Pasteur, who in the mid-1800s demonstrated that heating wine and beer prevented spoilage; the principle was later adapted to milk and other foods. Over time, as urbanization and longer transport distances increased the risk of pathogen growth in raw foods, pasteurization became a key public health intervention (often called one of the triumphs of 20th-century public health) to reduce milkborne and foodborne illnesses.

Importantly, pasteurization is **not cooking** — it does not aim to sterilize the food or significantly alter its nutritional or sensory properties. Instead, it applies a carefully controlled sub-sterilization treatment: raising the food (or liquid) to a critical temperature for a defined holding time, then cooling rapidly. For milk, the classical low-temperature, long-time (LTLT) method is 63 °C held for 30 minutes; the more common high-temperature, short-time (HTST) method is 72 °C maintained for 15 seconds. These parameters (or their equivalents) are chosen to inactivate non-spore-forming pathogens such as *Mycobacterium tuberculosis*, *Salmonella*, *Listeria*, *Campylobacter*, *E. coli*, and others, while preserving flavor, nutrients, and functionality. Ultra-high-temperature (UHT) methods going to ~138–150 °C for 1–2 seconds are also used (especially for shelf-stable milk), but require more stringent sterile packaging.

The principle extends beyond dairy. Pasteurization is used for fruit juices (e.g., apple or orange juice), egg products (liquid pasteurized eggs), and other beverages or foods that are sensitive to heat damage but still require microbial safety control. For example, pasteurized juice (often called “flash pasteurization”) brings juice to a high temperature (for example 71–75 °C) for a few seconds to kill *E. coli* or *Salmonella*. In egg processing, liquid egg products can be heated just enough to inactivate *Salmonella* without coagulating the proteins. In dairy, pasteurized milk, cream, yogurt, and cheese (when made from pasteurized milk) are meaningfully safer for consumption than raw milk. Through pasteurization, the microbial load is reduced to safe levels, significantly lowering the risk of foodborne illness while maintaining most of the nutritive value of the food.

By eliminating or greatly reducing pathogens, pasteurization increases the safety margin for sensitive consumers, allows safer transport and storage under refrigeration, and is a critical control point in modern food safety systems.

Is it a good idea to drink raw milk?

In recent years, a growing number of influencers, health bloggers, and advocates of 'natural' or ancestral diets have promoted raw milk consumption, often claiming benefits related to digestion, immunity, or nutritional superiority. Consuming raw (unpasteurized) milk carries well-documented risks. Raw milk may harbor pathogenic bacteria such as *Salmonella*, *E. coli* (including Shiga-toxin–producing strains), *Campylobacter*, *Listeria*, *Brucella*, and *Mycobacterium bovis*, among others. Even with excellent farm hygiene, contamination can occur via asymptomatic shedding by cows, contact with feces, faulty equipment, or environmental intrusion (e.g. on udder surfaces, milking equipment, or handlers).

Particularly concerning are severe outcomes in children, older adults, pregnant women, and immune-compromised individuals. In outbreak and surveillance studies, raw milk–associated *E. coli* infections have led to hemolytic uremic syndrome (HUS), acute kidney failure, and in some cases death. A Minnesota study of non-outbreak raw milk–associated illnesses found that 21% of

persons infected with STEC (Shiga-toxin–producing *E. coli*) who reported raw milk consumption developed HUS, and at least one such patient died. In addition, CDC regularly reports raw dairy outbreaks: for example, during October 2023–March 2024, a Salmonella Typhimurium outbreak traced to a raw milk dairy sickened 171 people (70 % children), with many hospitalizations. In older reviews, between 1993 and 2006, 121 outbreaks were linked to nonpasteurized dairy products (versus pasteurized), resulting in 1,571 illnesses, 202 hospitalizations, and 2 deaths.

Although rare in the literature are documented cases of chronic dialysis following raw milk infection, the severity of renal injury from HUS (especially in children) can necessitate prolonged dialysis or result in permanent renal damage in survivors. (Textbooks and case reports of HUS treatment describe some children requiring dialysis and long-term monitoring.) Public health authorities strongly discourage raw milk consumption because the benefits do not outweigh the known risks.

As a cautionary, although not directly a milk case, the 1996 outbreak of *E. coli* O157:H7 in unpasteurized Odwalla apple juice demonstrates the danger of raw-beverage consumption. In that outbreak, 70 people were sickened, 14 children developed HUS requiring dialysis, and a 16-month-old girl died of kidney failure. That tragedy led Odwalla to begin pasteurizing its juices afterward, and it is cited widely in food safety literature as a cautionary example.

In summary, while raw milk advocates sometimes cite presumed nutritional or probiotic advantages, the documented risks in vulnerable populations, the possibility of severe renal injury, and historical cases of deaths make raw milk a dangerous choice compared to the much safer alternative of pasteurized milk.

Food Irradiation: What You Need to Know

Irradiation does not make foods radioactive, compromise nutritional quality, or noticeably change the taste, texture, or appearance of food. In fact, any changes made by irradiation are so minimal that it is not easy to tell if a food has been irradiated.

Food irradiation (the application of ionizing radiation to food) is a technology that improves the safety and extends the shelf life of foods by reducing or eliminating microorganisms and insects. Like pasteurizing milk and canning fruits and vegetables, irradiation can make food safer for the consumer. The Food and Drug Administration (FDA) is responsible for regulating the sources of radiation that are used to irradiate food. The FDA approves a source of radiation for use on foods only after it has determined that irradiating the food is safe.

Why Irradiate Food?

Irradiation can serve many purposes.

- Prevention of Foodborne Illness – to effectively eliminate organisms that cause foodborne illness, such as Salmonella and E. coli.
- Preservation – to destroy or inactivate organisms that cause spoilage and decomposition and extend the shelf life of foods.
- Control of Insects – to destroy insects in or on tropical fruits imported into the United States. Irradiation also decreases the need for other pest-control practices that may harm the fruit.
- Delay of Sprouting and Ripening – to inhibit sprouting (e.g., potatoes) and delay ripening of fruit to increase longevity.
- Sterilization – irradiation can be used to sterilize foods, which can then be stored for years without refrigeration. Sterilized foods are useful in hospitals for patients with severely impaired immune systems, such as patients with AIDS or undergoing chemotherapy. Foods that are sterilized by irradiation are exposed to substantially higher levels of treatment than those approved for general use.

How Is Food Irradiated?

There are three sources of radiation approved for use on foods.

- Gamma rays are emitted from radioactive forms of the element cobalt (Cobalt 60) or of the element cesium (Cesium 137). Gamma radiation is used routinely to sterilize medical, dental, and household products and is also used for the radiation treatment of cancer.
- X-rays are produced by reflecting a high-energy stream of electrons off a target substance (usually one of the heavy metals) into food. X-rays are also widely used in medicine and industry to produce images of internal structures.
- Electron beam (or e-beam) is similar to X-rays and is a stream of high-energy electrons propelled from an electron

accelerator into food.

Is Irradiated Food Safe to Eat?

The FDA has evaluated the safety of irradiated food for more than 30 years and has found the process to be safe. The World Health Organization (WHO), the Centers for Disease Control and Prevention (CDC) and the U.S. Department of Agriculture (USDA) have also endorsed the safety of irradiated food.

The FDA has approved a variety of foods for irradiation in the United States including:

- Beef and Pork
- Crustaceans (e.g., lobster, shrimp, and crab)
- Fresh Fruits and Vegetables
- Lettuce and Spinach
- Poultry
- Seeds for Sprouting (e.g., for alfalfa sprouts)
- Shell Eggs
- Shellfish – Molluscan (e.g., oysters, clams, mussels, and scallops)
- Spices and Seasonings



Figure 14.6.1: Image by USDA / CC BY 4.0

How Will I Know if My Food Has Been Irradiated?

The FDA requires that irradiated foods bear the international symbol for irradiation. Look for the Radura symbol along with the statement “Treated with radiation” or “Treated by irradiation” on the food label. Bulk foods, such as fruits and vegetables, are required to be individually labeled or to have a label next to the sale container. The FDA does not require that individual ingredients in multi-ingredient foods (e.g., spices) be labeled. It is important to remember that irradiation is not a replacement for proper food handling practices by producers, processors, and consumers. Irradiated foods need to be stored, handled, and cooked in the same way as non-irradiated foods, because they could still become contaminated with disease-causing organisms after irradiation if the rules of basic food safety are not followed.[1]

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14.7: Food Processing

Food processing includes the methods and techniques used to transform raw ingredients into packaged food. Workers in this industry use harvested crops or slaughtered and butchered livestock to create products that are marketed to the public. There are different ways in which food can be processed, from a one-off product, such as a wedding cake, to a mass-produced product, such as a line of cupcakes packaged and sold in stores.

The Pros and Cons of Food Processing

Food processing has a number of important benefits, such as creating products that have a much longer shelf life than raw foods. Also, food processing protects the health of the consumer and allows for easier shipment and the marketing of foods by corporations. However, there are certain drawbacks. Food processing can reduce the nutritional content of raw ingredients. For example, canning involves the use of heat, which destroys the vitamin C in canned fruit. Also, certain food additives that are included during processing, such as high fructose corn syrup, can affect the health of a consumer. However, the level of added sugar can make a major difference. Small amounts of added sugar and other sweeteners, about 6 to 9 teaspoons a day or less, are not considered harmful.[1]



Figure 14.7.1: Image by Dean Hochman / CC BY 2.0

Food Additives

Food additives are substances intentionally added to food to enhance flavor, appearance, texture, preservation, or nutritional value. If you examine the label for a processed food product, it is not unusual to see a long list of added materials. These natural or synthetic substances are food additives and there are more than three hundred used during food processing today. The most popular additives are benzoates, nitrites, sulfites, and sorbates, which prevent molds and yeast from growing on food.[2] Food additives are introduced in the processing stage for a variety of reasons. Some control acidity and alkalinity, while others enhance the color or flavor of food. Some additives stabilize food and keep it from breaking down, while others add body or texture. Table 17.1 lists some common food additives and their uses:

Table 17.1 Food Additives

Additive	Reason for Adding
Beta-carotene	Adds artificial coloring to food

Additive	Reason for Adding
Caffeine	Acts as a stimulant
Citric acid	Increases tartness to prevent food from becoming rancid
Dextrin	Thickens gravies, sauces, and baking mixes
Gelatin	Stabilizes, thickens, or texturizes food
Modified food starch	Keeps ingredients from separating and prevents lumps
MSG	Enhances flavor in a variety of foods
Pectin	Gives candies and jams a gel-like texture
Polysorbates	Blends oil and water and keep them from separating
Soy lecithin	Emulsifies and stabilizes chocolate, margarine, and other items
Sulfites	Prevent discoloration in dried fruits
Xanthan gum	Thickens, emulsifies, and stabilizes dairy products and dressings

Source: Chemical Cuisine: Learn about Food Additives. Center for Science in the Public Interest.http://www.cspinet.org/reports/chemcuisine.htm. Published 2012. Accessed January 20, 2018.

Food Additives in the U.S. and the E.U.: A Comparative Overview

Although the global food industry often uses similar processing techniques, the regulatory landscape governing food additives differs significantly between regions — most notably between the **United States** and the **European Union (E.U.)**.

Regulatory Framework

In the **United States**, food additives are regulated by the **Food and Drug Administration (FDA)** under the **Federal Food, Drug, and Cosmetic Act (FFDCA)**. Additives must either be approved by the FDA or classified as **Generally Recognized As Safe (GRAS)** based on scientific evidence or a history of safe use.

In contrast, the **European Union** regulates food additives under **Regulation (EC) No. 1333/2008**, overseen by the **European Food Safety Authority (EFSA)**. Additives in the E.U. are identified by "E numbers" and must undergo rigorous safety assessments. The E.U. generally applies the **precautionary principle**, meaning that substances are not approved unless there is strong evidence of safety.

Key Differences: Additives Approved in the U.S. but Banned or Restricted in the E.U.

Additive	U.S. Status	E.U. Status	Primary Use	Concerns in the E.U.
Potassium Bromate	Allowed in bread and baked goods	Banned	Dough strengthener	Possible carcinogenicity
Azodicarbonamide (ADA)	Permitted in flour-based products	Banned	Dough conditioner	Links to respiratory issues and breakdown into carcinogenic byproducts
Brominated Vegetable Oil (BVO)	Permitted in some citrus-flavored sodas (restricted in use)	Banned	Emulsifier in beverages	Accumulation in body fat, potential reproductive and neurological harm

Additive	U.S. Status	E.U. Status	Primary Use	Concerns in the E.U.
Propylparaben	Allowed as a preservative	Banned	Preservative in baked goods and some cosmetics	Endocrine disruption
Artificial Colors (e.g., Red 40, Yellow 5)	Widely used	Permitted with warning labels or restricted	Food dyes in candies, drinks, cereals	Hyperactivity in children, synthetic origin
rBGH / rBST (Recombinant Bovine Growth Hormone)	Used in dairy production	Banned	Increases milk production	Animal welfare, potential links to cancer risk via IGF-1 hormone levels

Why the Differences? — Underlying Philosophies and Consumer Impact

The key divergence lies in the **risk assessment philosophy**. The **U.S. model emphasizes benefit-risk balancing**, often allowing substances unless proven harmful. In contrast, the **E.U. adopts a more cautious stance**, erring on the side of consumer safety and public concern.

These regulatory differences have implications for **consumer trust, food imports, labeling practices,** and **industry formulation standards**. For instance, some U.S.-based companies reformulate products sold in Europe to comply with stricter additive regulations — highlighting the potential for international harmonization based on evolving scientific evidence and consumer advocacy.

The Pros and Cons of Food Additives

One beneficial food additive covered already is the practice of food fortification — a well-established and effective public health strategy, which involves adding essential nutrients to widely consumed food vehicles. This approach plays a critical role in addressing population-wide deficiencies of nutrients that are often difficult to obtain in adequate amounts through diet alone — such as iodine, folate, and vitamin D in the United States. By enhancing the nutritional quality of staple foods, fortification helps prevent nutrient-related health issues on a broad scale and supports overall public health outcomes.

The FDA works to protect the public from potentially dangerous additives. Passed in 1958, the Food Additives Amendment states that a manufacturer is responsible for demonstrating the safety of an additive before it can be approved. The Delaney Clause that was added to this legislation prohibits the approval of any additive found to cause cancer in animals or humans. However, most additives are considered to be “generally recognized as safe,” a status that is determined by the FDA and referred to as GRAS.

Food additives are typically included in the processing stage to improve the quality and consistency of a product. Many additives also make items more “shelf stable,” meaning they will last a lot longer on store shelves and can generate more profit for store owners. Additives can also help to prevent spoilage that results from changes in temperature, damage during distribution, and other adverse conditions. In addition, food additives can protect consumers from exposure to rancid products and foodborne illnesses.

Food additives aren’t always beneficial, however. Some substances have been associated with certain diseases if consumed in large amounts. For example, the FDA estimates that sulfites can cause allergic reactions in 1 percent of the general population and in 5 percent of asthmatics.

Nitrates and Nitrites

Nitrates (NO_3^-) and nitrites (NO_2^-) are added to cured meats for three main reasons:

1. **Preventing foodborne illness**: Nitrites inhibit *Clostridium botulinum*, the bacterium that causes botulism — a rare but deadly form of food poisoning.
2. **Preserving color and flavor**: Nitrites stabilize the red/pink color of cured meats and prevent rancidity.
3. **Extending shelf life**: They act as antioxidants, slowing spoilage.

Without these additives, the risk of serious microbial contamination increases significantly.

Cancer Risk and the IARC Classification

The International Agency for Research on Cancer (IARC) has classified **processed meats** as **Group 1 carcinogens** (known to cause cancer), and **nitrates/nitrites under conditions that lead to endogenous nitrosation** as **Group 2A (probably carcinogenic to humans)**. This is due to the formation of N-nitroso compounds, which are known carcinogens in animals and potentially in humans.

Epidemiological studies show a link between high consumption of processed meats and colorectal cancer. However, risk depends on dose, diet, and context.

Weighing the Risks

While there is a potential long-term cancer risk from chronic exposure to nitrites, the **immediate danger of botulism** is far greater. Public health authorities allow limited use of these additives because preventing acute, potentially fatal illness outweighs the small increase in lifetime cancer risk for most people.

The "Natural" Loophole: Celery Juice

Some products marketed as "no nitrates or nitrites added" use **celery juice or powder**, which naturally contains high levels of nitrate. In the body or during curing, this nitrate converts to nitrite and behaves **chemically the same** as synthetic forms.

So-called "natural" products may still expose consumers to similar levels of nitrites — they're simply derived from plants rather than industrial salts. The health risks are essentially the same, despite more appealing labels.

MSG

Although monosodium glutamate (MSG) has historically been associated with adverse symptoms such as headaches, nausea, and chest discomfort — a set of complaints popularly labeled as "Chinese Restaurant Syndrome" — these claims have not been substantiated by placebo-controlled clinical trials. The U.S. Food and Drug Administration, along with numerous scientific reviews, has affirmed the safety of MSG as a food additive. The persistence of negative perceptions surrounding MSG is widely recognized as being rooted in xenophobic and racially biased narratives, particularly targeting Chinese and other Asian cuisines. Consequently, Asian restaurants are disproportionately pressured to disavow the use of MSG in their cooking, a burden not typically placed on non-Asian establishments that use the same additive.

Food colorings

Since 2025, discussions around the use of artificial food dyes have intensified — here are some key recent developments:

- The FDA still permits Red 40 (under 21 CFR 74.340) when used in accordance with its regulations and purity standards.
- What *has* changed recently is that **Red No. 3 (FD&C Red No. 3)** was revoked (i.e. its authorization withdrawn) for use in food and dietary supplements, with a transition period for manufacturers to reformulate.
- Moreover, in April 2025, the U.S. Department of Health & Human Services (HHS) and FDA announced plans to **phase out** petroleum-based synthetic dyes — including Red 40, Yellow 5, Yellow 6, Blue 1, Blue 2, and Green 3 — from the food supply by the end of 2026. But as of now, these are proposals / planned phase-outs, not full bans.
- Some states have already taken action: e.g., California has banned Red 40 and other synthetic dyes in foods sold in public schools.

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14.8: The Effect of New Technologies

As mentioned earlier, new technology has had a tremendous effect on the food we eat and the customs and culture related to food consumption. For example, microwaves are used to reduce cooking time or to heat up leftover food. Refrigerators and freezers allow produce to travel great distances and last longer. On the extreme end of making food last longer, there is special food for astronauts that is appropriate for consumption in space. It is safe to store, easy to prepare in the low-gravity environment of a spacecraft, and contains balanced nutrition to promote the health of people working in space. In the military, soldiers consume Meals Ready-to-Eat (MREs), which contain an entire meal in a single pouch.

Consumer Info About Food From Genetically Engineered Plants

FDA regulates the safety of food for humans and animals, including foods produced from genetically engineered (GE) plants. Foods from GE plants must meet the same food safety requirements as foods derived from traditionally bred plants. Read more at Consumer Info About Food From Genetically Engineered Plants.[1]

Genetically Modified Foods

Genetically modified foods (also known as GM or GMO foods), are plants or animals that have undergone some form of genetic engineering. In the United States, much of the soybean, corn, and canola crop is genetically modified. The process involves the alteration of an organism's DNA, which allows farmers to cultivate plants with desirable characteristics.[2] For example, scientists could extract a gene that produces a chemical with antifreeze properties from a fish that lives in an arctic region (such as a flounder). They could then splice that gene into a completely different species, such as a tomato, to make it resistant to frost, which would enable farms to grow that crop year-round.[3]

Certain modifications can be beneficial in resisting pests or pesticides, improving the ripening process, increasing the nutritional content of food, or providing resistance to common viruses. Although genetic engineering has improved productivity for farmers, it has also stirred up debate about consumer safety and environmental protection. Possible side effects related to the consumption of GM foods include an increase in allergenicity, or tendencies to provoke allergic reactions. There is also some concern related to the possible transfer of the genes used to create genetically engineered foods from plants to people. This could influence human health if antibiotic-resistant genes are transferred to the consumer. Therefore, the World Health Organization (WHO) and other groups have encouraged the use of genetic engineering without antibiotic-resistance genes. Genetically modified plants may adversely affect the environment as well and could lead to the contamination of non-genetically engineered organisms.[4]

Genetically modified foods fall under the purview of the EPA, the USDA, and the FDA. Each agency has different responsibilities and concerns in the regulation of GM crops. The EPA ensures that pesticides used for GM plants are safe for the environment. The USDA makes sure genetically engineered seeds are safe for cultivation prior to planting. The FDA determines if foods made from GM plants are safe to eat. Although these agencies act independently, they work closely together and many products are reviewed by all three.[5]

A Way Forward?

As global challenges like climate change, population growth, and shrinking arable land intensify, genetically modified organisms (GMOs) and gene-editing technologies offer powerful tools to help sustainably feed an estimated 10 billion people by 2050. Innovations in genetic engineering now allow scientists to create crops that require less water, tolerate extreme weather, and even produce their own fertilizer by capturing nitrogen from the air — a process that could significantly reduce dependence on synthetic fertilizers and lower greenhouse gas emissions.

Additionally, certain GM crops are designed to require fewer pesticides, which lessens the environmental and health risks associated with chemical runoff. The broader application of gene-editing also extends beyond agriculture: for example, insulin, once extracted from animal pancreases, is now efficiently produced by genetically engineered microorganisms, offering a cleaner, more ethical, and scalable method of production. These advances demonstrate the technology's immense promise — not only to improve efficiency and reduce environmental impact, but also to reshape entire industries toward more humane and sustainable

practices. However, the real question lies not in the science, but in access and application: Who controls and implements these technologies? Who profits? And who truly benefits?

To explore these complex questions and gain a deeper understanding of the science and societal impact of genetic engineering, watch the video *Are GMOs Good or Bad? Genetic Engineering & Our Food* by Kurzgesagt – In a Nutshell. This animated explainer breaks down the debate around GMOs in a clear, engaging, and scientifically grounded way. It covers how genetic modification works, the potential benefits and risks, and some of the broader ethical and economic questions. Could GMO food be the new 'organic'?

YouTube Video

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Video 14.8.1: *Are GMOs Good or Bad? Genetic Engineering & Our Food* by Kurzgesagt. March 30, 2017. Available at https://youtu.be/7TmcXYp8xu4?si=m08OEdHf1VtYRxP7

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14.9: Efforts on the Consumer Level — What You Can Do

Consumers can also take steps to prevent foodborne illness and protect their health. Although you can often detect when mold is present, you can't see, smell, or taste bacteria or other agents of foodborne disease. Therefore, it is crucial to take measures to protect yourself from disease. The four most important steps for handling, preparing, and serving food are[1]:

- **Clean.** Wash hands thoroughly. Clean surfaces often and wash utensils after each use. Wash fruits and vegetables (even if you plan to peel them).
- **Separate.** Don't cross-contaminate food during preparation and storage. Use separate cutting boards for produce and for meat, poultry, seafood, and eggs. Store food products separately in the refrigerator.
- **Cook.** Heat food to proper temperatures. Use a food thermometer to check the temperature of food while it is cooking. Keep food hot after it has been cooked.
- **Chill.** Refrigerate any leftovers within two hours. Never thaw or marinate food on the counter.

Know when to keep food and when to throw it out. It can be helpful to check the website http://www.stilltasty.com, which explains how long refrigerated food remains fresh.

Buying Food

It is best to buy your food from reputable grocers with clean, sanitary facilities, that keep products at appropriate temperatures. Consumers should examine food carefully before they purchase it. It is important to look at food in glass jars, check the stems on fresh produce, and avoid bruised fruit. Do not buy canned goods with dents or bulges, which are at risk for contamination with Clostridium botulinum. Fresh meat and poultry are usually free from mold, but cured and cooked meats should be examined carefully. Also, avoid torn, crushed, or open food packages, and do not buy food with frost or ice crystals, which indicates that the product has been stored for a long time, or thawed and refrozen. It is also a good idea to keep meat, poultry, seafood, and eggs separate from other items in your shopping cart as you move through the grocery store.

Storing Food

Refrigerate perishable foods quickly; they should not be left out for more than two hours. The refrigerator should be kept at 40°F (or 4°C) or colder, and checked periodically with a thermometer. Store eggs in a carton on a shelf in the refrigerator, and not on the refrigerator door where the temperature is warmest. Wrap meat packages tightly and store them at the bottom of the refrigerator, so juices won't leak out onto other foods. Raw meat, poultry, and seafood should be kept in a refrigerator for only two days. Otherwise, they should be stored in the freezer, which should be kept at 0°F (or –18°C). Store potatoes and onions in a cool, dark place, but not under a sink because leakage from pipes could contaminate them. Empty cans of perishable foods or beverages that have been opened into containers, and promptly place them in a refrigerator. Also, be sure to consume leftovers within three to five days, so mold does not have a chance to grow.

Preparing Food

Wash hands thoroughly with warm, soapy water for at least twenty seconds before preparing food and every time after handling raw foods. Washing hands is important for many reasons. One is to prevent cross-contamination between foods. Also, some pathogens can be passed from person to person, so hand washing can help to prevent this. Fresh fruits and vegetables should also be rinsed thoroughly under running water to clean off pesticide residue[2].

This is particularly important for produce that contains a high level of residue, such as apples, pears, spinach, and potatoes. Washing also removes most dirt and bacteria from the surface of produce.

Other tips to keep foods safe during preparation include defrosting meat, poultry, and seafood in the refrigerator, microwave, or in a water-tight plastic bag submerged in cold water. Never defrost at room temperature because that is an ideal temperature for bacteria to grow. Also, marinate foods in the refrigerator and discard leftover marinade after use because it contains raw juices. Always use clean cutting boards, which should be washed with soap and warm water by hand or in a dishwasher after each use. Another way to sanitize cutting boards is to rinse them with a solution of 5 milliliters (1 teaspoon) chlorine bleach to about 1 liter

(1 quart) of water. If possible, use separate cutting boards for fresh produce and for raw meat. Also, wash the top before opening canned foods to prevent dirt from coming into contact with food.

Cooking Food

Cooked food is safe to eat only after it has been heated to an internal temperature that is high enough to kill bacteria. You cannot judge the state of "cooked" by color and texture alone. Instead, use a food thermometer to be sure. The appropriate minimum cooking temperature varies depending on the type of food:

- Whole cuts of beef, veal, lamb, and pork, including fresh ham: 145°F (then allow the meat to rest for 3 minutes before carving or eating)
- Fish with fins: 145°F or cook until the flesh is opaque and separates easily with a fork
- Ground meats, such as beef and pork: 160°F
- All poultry, including ground chicken and turkey: 165°F
- Leftovers and casseroles: 165°F

When microwaving, rotate the dish and stir contents several times to ensure even cooking.

Serving Food

After food has been cooked, the possibility of bacterial growth increases as the temperature drops. So, food should be kept above the safe temperature of 140°F, using a heat source such as a chafing dish, warming tray, or slow cooker. Cold foods should be kept at 40°F or lower. When serving food, keep it covered to block exposure to any mold spores hanging in the air. Use plastic wrap to cover foods that you want to remain moist, such as fresh fruits, vegetables, and salads. After a meal, do not keep leftovers at room temperature for more than two hours. They should be refrigerated as promptly as possible. It is also helpful to date leftovers, so they can be used within a safe time, which is generally three to five days when stored in a refrigerator.

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