INTRODUCTION TO NUTRITION SCIENCE



Bisson et. al

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Glossary

Glossary

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Licensing

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CHAPTER OVERVIEW

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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:
Photo by Tim Mossholder / Unsplash



Figure 1.1.2:
Photo by National Cancer Institute / Unsplash

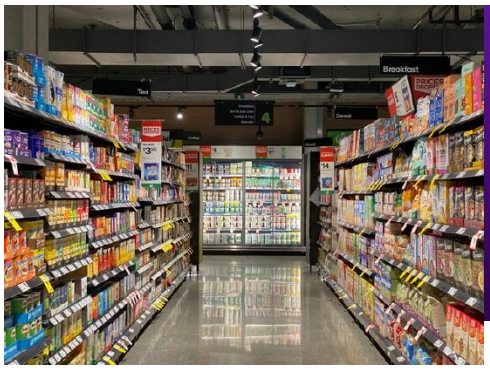


Figure 1.1.3:
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Figure 1.1.4:
Photo by Ella Olsson / Unsplash

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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1.2: 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 technically nutrients, but many have been shown to affect human health.)



Figure 1.2.1: 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.

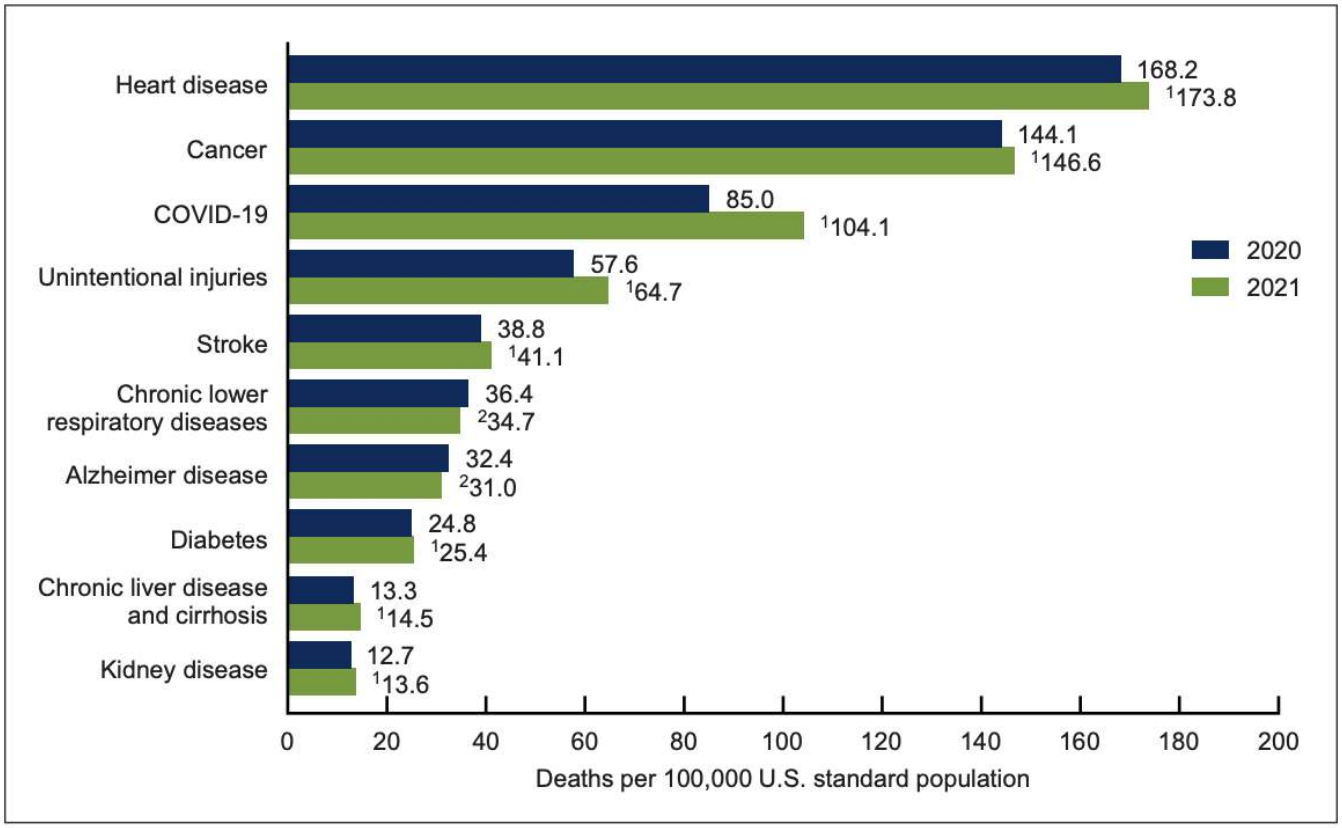
As you read about nutrition and health, you may see many references to the term "diet". In popular culture, this word is often associated with restrictive eating plans, food or beverage limitations, or rigid eating schedules. However, in the context of nutrition science, the term **diet** simply refers 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 associated with four of the top ten leading causes of death in the United States, including heart disease, cancer, stroke, and diabetes.[5]



[1]Statistically significant increase from 2020 to 2021 ($p < 0.05$). [2]Statistically significant decrease from 2020 to 2021 ($p < 0.05$).

NOTES: A total of 3,464,231 resident deaths were registered in the United States in 2021. The 10 leading causes of death accounted for 74.5% of all U.S. deaths in 2021. Causes of death are ranked according to number of deaths. Rankings for 2020 data are not shown. Data table for Figure 4 includes the number of deaths for leading causes and the percentage of total deaths. Access data table for Figure 4 at: https://www.cdc.gov/nchs/data/databr...6-tables.pdf#4. SOURCE: National Center for Health Statistics, National Vital Statistics System, Mortality.

Figure 1.2.2: Age-adjusted death rates for the 10 leading causes of death: United States, 2020 and 2021 "Mortality in the United States, 2021" 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 1.2.3: 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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1.3: 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, you must 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. On this page, we'll zoom in to understand how atoms bond together to form these chemical molecules.



Figure 1.3.1: "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.

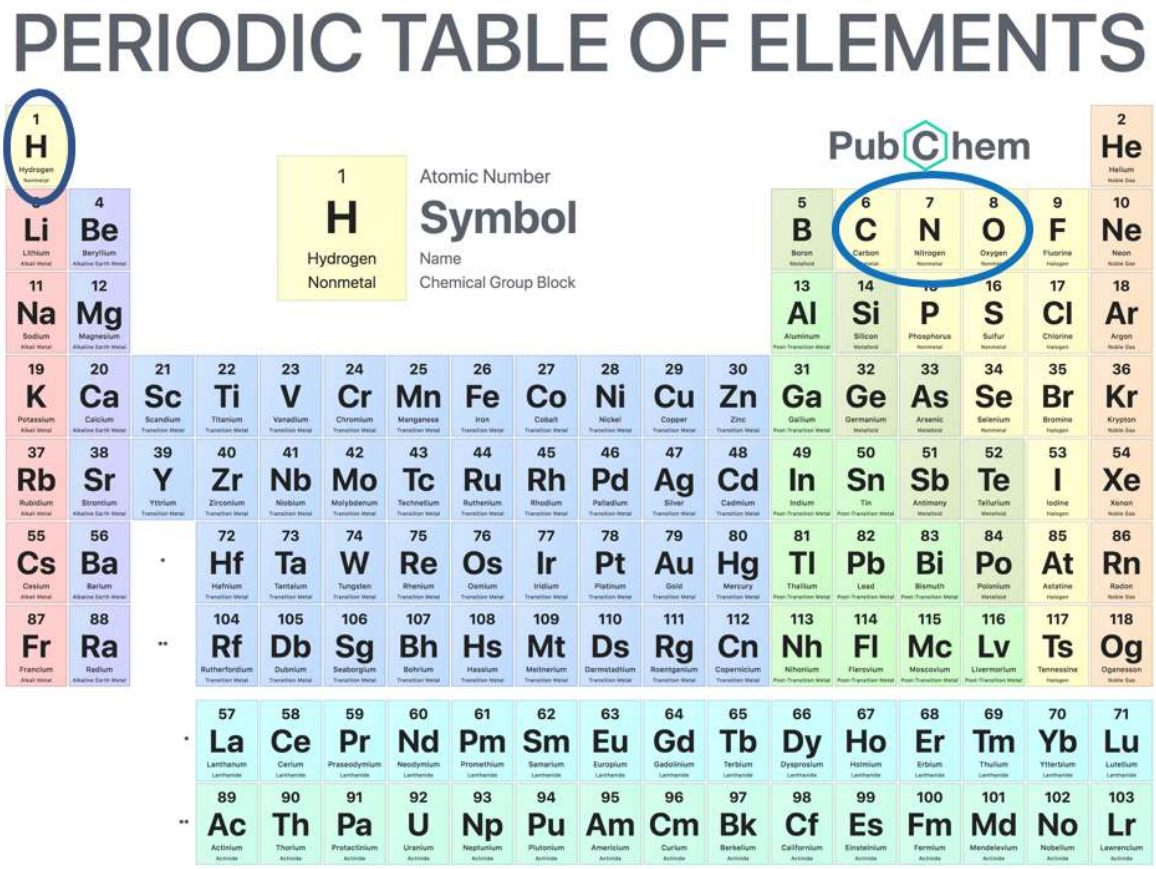


Figure 1.3.2: "Periodic Table of Elements" by Heather Leonard, CC BY-NC 4.0, edited from photo by "Periodic Table of Elements" by PubChem, U.S. National Library of Medicine is in the Public Domain

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.

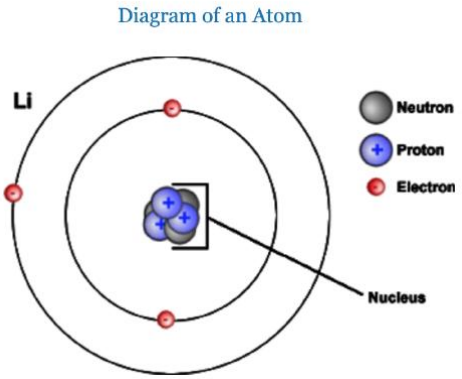


Figure 1.3.3: Diagram of a lithium atom, showing the placement of protons, neutrons, and electrons. Protons and neutrons are found in the nucleus (center) of the atom. Electrons are found outside the nucleus. "Diagram of an Atom" from "Introduction to Biology" by Open Learning Initiative is licensed 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.

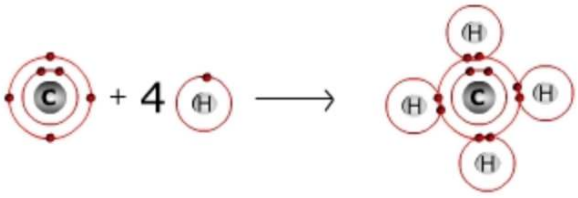
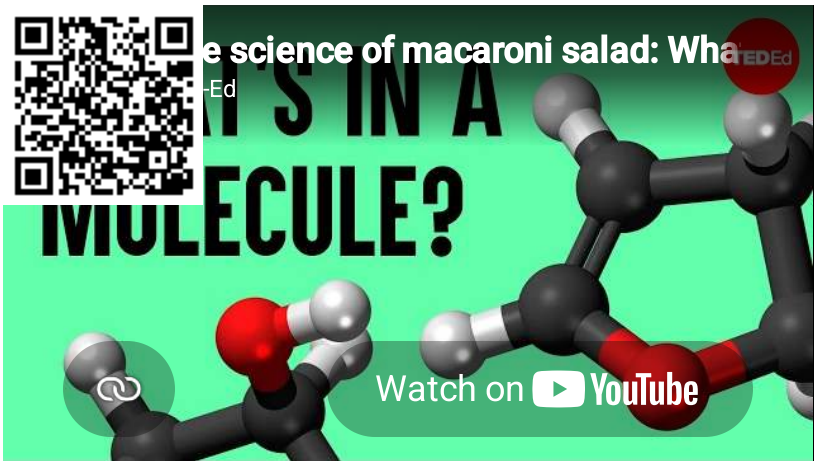


Figure 1.3.4: A molecule of methane. Carbon and hydrogen react to form methane by sharing electrons through a covalent bond. "Formation of Methane" from "Introduction to Biology" by Open Learning Initiative is licensed under CC BY-NC-SA 4.0

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.



Video 1.3.1: 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 1.3.5: 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 make up the nutrients you ingest every time you eat. In this way, 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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1.4: Overview of Nutrients and Calories

Learning Objectives

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

What 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 essential nutrients required for the body to function and maintain overall health. These six classes of essential nutrients are: carbohydrates, lipids (fats), proteins, water, vitamins, and minerals.

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.

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

Table 1.4.1: 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). Provide structural constituents for the formation of cells.
Lipids (Fats)	Provide stored energy for the body. Function as structural components of cells and also as signaling molecules for proper cellular communication. Provide insulation to vital organs and works to maintain body temperature.
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.
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.
Minerals	Regulate body processes, are necessary for proper cellular function, and comprise body tissue.

Macronutrients

Nutrients that are needed in large amounts are called macronutrients. Macronutrients include carbohydrates, lipids (fats), proteins, and water. Carbohydrates, lipids, and proteins provide energy (calories) which can be used ("burned") by your body to perform basic functions. The energy from these macronutrients comes from their chemical bonds. This chemical energy is converted into cellular energy that is then utilized to perform work, allowing our bodies to conduct their basic functions. Water is needed in large quantities but does not contain energy (calories).

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, 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, and regulate many other functions in the body.

Proteins

Major food sources of proteins include meats, dairy products, seafood, and a variety of different plant-based foods (e.g., soy). 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, 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 1.4.2 and 1.4.3 for a complete list and their major functions). In contrast to carbohydrates, lipids, and proteins, micronutrients do not contain calories. This is often confusing because most people have heard how tired a person will feel if they are low in a micronutrient such as Iron. The tiredness can be explained by the fact that, micronutrients assist in the process of making energy by being part of enzymes (i.e., coenzymes). Enzymes catalyze (cause or speed up) chemical reactions in the body and are involved in many aspects of body functions from producing energy, to digesting nutrients, to building macromolecules.

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

Table 1.4.2: 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

Vitamins	Major Functions
B_{12} (cobalamin)	Coenzyme, red blood cell synthesis
C	Collagen synthesis, antioxidant
Fat-soluble	
A	Vision, reproduction, immune system function
D	Bone and teeth health maintenance, immune system function
E	Antioxidant, cell membrane protection
K	Bone and teeth health maintenance, blood clotting

The following video provides a nice overview of vitamins:



Video 1.4.1: 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 a few milligrams or less and macrominerals, such as calcium, magnesium, potassium, sodium, and phosphorus, are required in hundreds of milligrams. Many minerals are critical for enzyme function, others are used to maintain fluid balance, build bone tissue, synthesize hormones, transmit nerve impulses, contract and relax muscles, and protect against harmful free radicals.

Table 1.4.3: : Minerals and Their Major Functions

Minerals	Major Functions
Macro	
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

Minerals	Major Functions
Zinc	Protein and DNA production, wound healing, growth, immune system function
Iodine	Thyroid hormone production, growth, metabolism
Selenium	Antioxidant
Copper	Coenzyme, iron metabolism
Manganese	Coenzyme
Fluoride	Bone and teeth health maintenance, tooth decay prevention
Chromium	Assists insulin in glucose metabolism
Molybdenum	Coenzyme

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

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 scientific instrument called a bomb calorimeter and measuring the energy output (energy = heat produced).

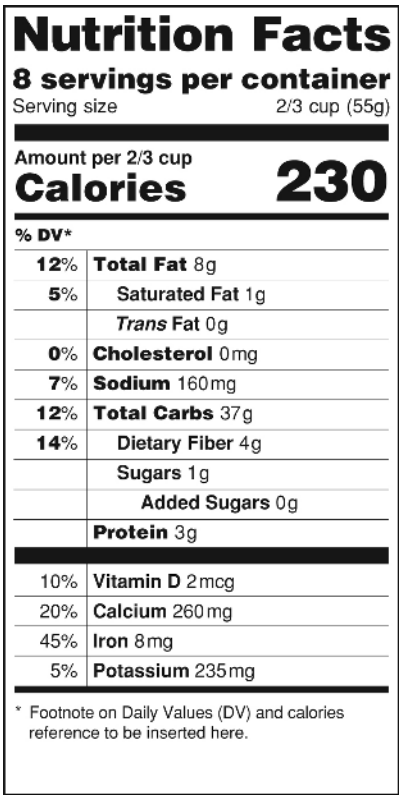
In the US, the kilocalorie (kcal) is the most commonly used unit of energy and is often just referred to as a calorie. Strictly speaking, a kcal is 1000 calories. In nutrition, the term calories almost always refers to kcals. Sometimes the kcal is indicated by capitalizing calories as “Calories.” For 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 1.4.1: "FDA Nutrition Facts Label" by USDA Food and Drug Administration is in the Public Domain

Example 1.4.1: 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 1.4.2: 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.



Video 1.4.2: 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.

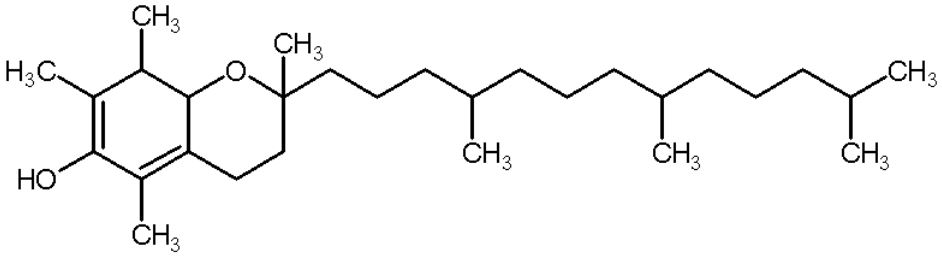


Figure 1.4.2: "Vitamin E" by Annabel is licensed under CC BY-SA 3.0

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.

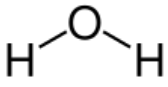


Figure 1.4.3: "Skeletal Structure of Water" by TSOL is licensed under CC BY-SA 4.0

Summary

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

Table 1.4.4: “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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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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1.5: 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.

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)

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
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

Metric System	US Customary System	Conversions
Kilometer (km)	Mile (mi)	1 mi = 1.6 km



Video 1.5.1: Math Antics - Intro to the Metric System. Available at https://youtu.be/ZNX-a-5jGeM



Figure 1.5.1:
One 8-ounce cup of liquid is about 240 milliliters.
One cup of orange juice by Bruno /Germany / Pixabay



Figure 1.5.2:
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 1.5.3:
A teaspoon of sugar weighs 4 grams.
Cinnamon Sugar by Ulrike Leone / Pixabay

Example 1.5.1: 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)

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1.6: 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%.

References

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

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1.7: 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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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 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 fresh, natural whole foods fuels the body by providing what it needs to produce energy, promote metabolic activity, prevent micronutrient deficiencies, ward off chronic disease, and to promote a sense of overall health and well-being.

Table 2.1.1: Why Nutrition Is Important to Health

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

Water	Transports essential nutrients to all body parts, transports waste products for disposal, and aids with body temperature maintenance.

Undernutrition, Overnutrition, and Malnutrition

For many, the word “malnutrition” produces an image of a child in a developing nation with a bloated belly, and skinny arms and legs. However, this image alone is not an accurate representation of the state of malnutrition. For example, someone who is 150 pounds overweight can also be malnourished. **Malnutrition** refers to one not receiving proper nutrition and does not distinguish between the consequences of too many nutrients or the lack of nutrients, both of which impair overall health. **Undernutrition** is characterized by a lack of nutrients and insufficient energy supply, whereas **overnutrition** is characterized by excessive nutrient and energy intake. Overnutrition can result in obesity. Obesity is defined as a metabolic disorder of an overaccumulation of fat tissue.

Although not as prevalent in America as it is in developing countries, undernutrition is not uncommon and affects many sub-populations, including the elderly, those with certain diseases, and those in poverty. Many people who live with diseases either have no appetite or may not be able to digest food properly. Some medical causes of malnutrition include cancer, inflammatory bowel 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. Overnutrition is an epidemic in the United States and is known to be a risk factor for many diseases, including Type 2 diabetes, cardiovascular disease, inflammatory disorders (such as rheumatoid arthritis), and cancer.

Growth and Development

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

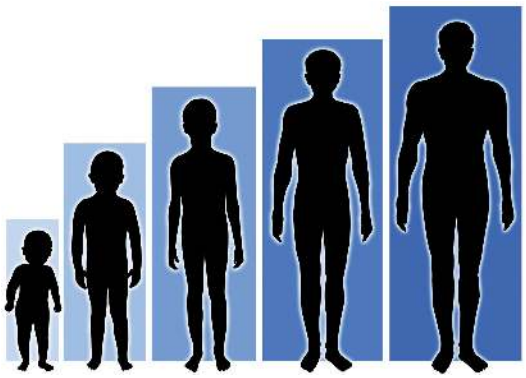


Figure 2.1.2: Proper growth throughout the life stages depends upon proper nutrition. © Dreamstime

The Healing Process

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

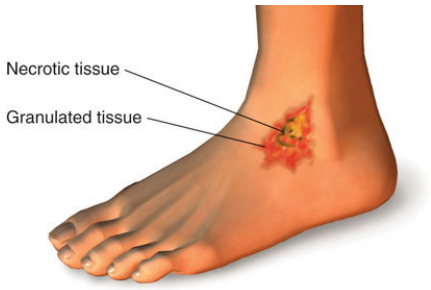


Figure 2.1.3: Healing, a critical function of a healthy body, is facilitated by adequate nutrition.

- **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 proper 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. Malnutrition results when the body does not receive the required 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?

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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 dieted, we are more likely to diet or develop an eating disorder. If the people we ate with as a child ate only packaged food, 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 may influence the food choices you make, but there are a number of other factors that affect the dietary choices individuals make.

Factors that Influence Food Choices

- **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?

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2.3: 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. 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 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 diets do 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 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 from a product that is proven not to work.

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]

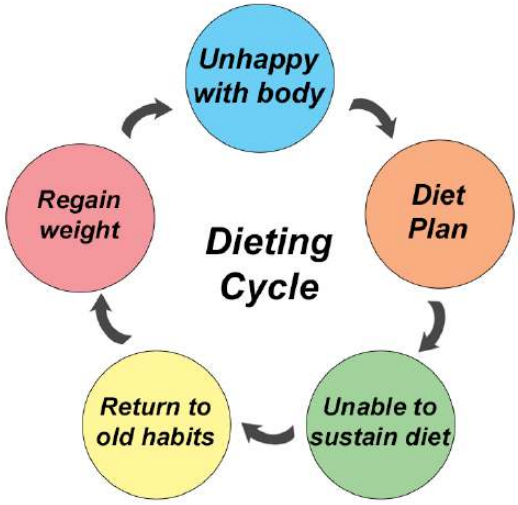


Figure 2.3.2: Image by Kellie Taguchi / CC BY 4.0

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] The results of multiple studies have indicated that using weight 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 2.3.3: Image by 272447 / Pixabay License

The following are measurable risk factors and markers of health that are not connected to 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
- 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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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] 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. 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 healthy, whole foods first, while adopting a more active lifestyle, rather than strictly cutting calories. These sound practices put dietary choices in the context of wellness and a healthier approach to life.

Functional Foods

Many people seek out foods that provide the greatest health benefits. This trend is giving rise to the idea of **functional foods**, which not only help meet basic nutritional needs but also are reported to fight illness and aging. According to the Academy of Nutrition and Dietetics (AND), formerly known as the 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, regarding the effects of modified foods on your health.

Medical foods are designed for enteric administration under the guidance of a medical professional. (During enteric administration, food is treated so that it goes through the stomach undigested. Instead, the food is broken down in the intestines only.) Medical foods are created to meet very specific nutritional requirements. Examples of medical foods include liquid formulas for people with kidney disease, liver disease, diabetes, or other health issues. Medical food is also given to comatose patients through a gastronomy tube because they cannot eat by mouth.

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

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.

The DASH Diet

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

DASH tips to lower sodium include:

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

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

The Gluten-Free Diet

The gluten-free diet helps people whose bodies cannot tolerate gluten, a protein found in wheat, barley, and rye. One of the most important ways to treat this condition is to avoid 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 only 1 percent of the population. Therefore, a gluten-free diet should be followed only with a physician's recommendation.

Low-Carb Diets

Low-carb diets, which include the Atkins Diet and the South Beach Diet, focus on limiting carbohydrates—such as grains, fruit, and starchy vegetables—to promote weight loss. 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 theory behind the low-carb diet is that insulin prevents the breakdown of fat by allowing sugar in the form of blood glucose to be used for energy. Proponents of this approach believe that because limiting 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]



Figure 2.4.1: What is a Healthy Diet? (used with permission; Registered Dietitian Libby Parker)

Link: https://youtu.be/AS0Pk3Z6gWM

The Mediterranean Diet

The traditional Mediterranean diet incorporates many elements of the dietary choices of people living in Greece and southern Italy. The Mediterranean diet focuses on small portions of nutritionally-sound food. This diet features food from plant sources, including vegetables, fruits, whole grains, beans, nuts, seeds, breads, potatoes, and olive oil. It also limits the consumption of processed foods and recommends eating locally grown foods rich in micronutrients and antioxidants. Other aspects of this eating plan include consuming fish and poultry at least twice per week, eating red meat only a few times per month, having up to seven eggs per week, and drinking red wine in moderation. Unlike most diets, the Mediterranean diet does not cut fat consumption across the board. Instead, it incorporates low-fat cheese and dairy products, and it substitutes olive oil, canola oil, and other healthy oils for butter and margarine.

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

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]

The Raw Food Diet

The raw food diet is followed by those who avoid cooking as much as possible in order to take advantage of the full nutrient content of foods. The principle behind raw foodism is that plant foods in their natural state are the most wholesome for the body.

The raw food diet is not a weight-loss plan, it is a lifestyle choice. People who practice raw foodism eat only uncooked and unprocessed foods, emphasizing whole fruits and vegetables. Staples of the raw food diet include whole grains, beans, dried fruits, seeds and nuts, seaweed, sprouts, and unprocessed produce. As a result, food preparation mostly involves peeling, chopping, blending, straining, and dehydrating fruits and vegetables.

The positive aspects of this eating method include consuming foods that are high in fiber and nutrients, and low in calories and saturated fat. However, the raw food diet offers little in the way of protein (especially if the consumer cannot eat nuts), and may create 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. 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 since it is made by bees.

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

Table 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
Gluten-Free Diet	• Reduces the symptoms of gluten intolerance, such as chronic diarrhea, cramping, constipation, and bloating • Promotes healing of the small intestines for people with celiac disease, preventing malnutrition • May be beneficial for other autoimmune diseases, such as Parkinson’s disease, rheumatoid arthritis, and multiple sclerosis	• Risk of folate, iron, thiamin, riboflavin, niacin, and vitamin B6 deficiencies • Special gluten-free products can be hard to find and expensive • Requires constant vigilance and careful food label reading, since gluten is found in many products

Diet	Pros	Cons
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 • May increase risk of heart disease
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 monosaturated fats leads to lower cholesterol • Highlighting fruits and vegetables raises consumption of antioxidants	• Does not specify daily serving amounts • Potential for high fat and high-calorie intake as nuts and oils are calorie-dense foods • Drinking one to two glasses of wine per day may not be healthy for those with certain conditions
Raw Food Diet	• Emphasizes whole foods • Focuses on nutritionally-rich foods	• Not entirely evidence-based • Very restrictive and limits protein and healthy fat intake • Could encourage the development of foodborne illness • Extremely difficult to follow • High in fiber which can cause essential nutrient deficiencies • Some foods have more nutrition when cooked
Vegetarianism and Veganism	• May reduce some chronic diseases such as cancer, heart disease, and Type 2 diabetes • More sustainable for the planet	

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 may be convenient and 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 or even pressured into spending money under the false perception that these products are necessary for proper nutrition. 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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2.5: Eating Disorders

Learning Objectives

Define the four main types of eating disorders.

List the health professionals on an eating disorder treatment team.

What are eating disorders? (1,2)

There is a commonly held misconception that eating disorders are a lifestyle choice. **Eating disorders** are serious medical illnesses marked by severe disturbances to a person's eating behaviors and related thoughts and emotions. Obsessions with food, body weight, and shape may be signs of an eating disorder. These disorders can affect a person's physical and mental health; in some cases, they can be life-threatening. But eating disorders can be treated. Learning more about them can help you spot the warning signs and seek treatment early. Common eating disorders include anorexia nervosa, bulimia nervosa, binge-eating disorder, and other specified feeding and eating disorders (OSFED).

Remember: Eating disorders are ***not*** a lifestyle choice. They are biologically-influenced medical and mental health illnesses.

Who is at risk for eating disorders?

Eating disorders can affect people of all ages, racial/ethnic backgrounds, body weights, and genders. Although eating disorders often appear during the teen years or young adulthood, they may also develop during childhood or later in life.

Remember: People with eating disorders may appear healthy, yet be extremely ill. You cannot tell if someone has an eating disorder by looking at them.

The exact cause of eating disorders is not fully understood, but research suggests a combination of genetic, biological, behavioral, psychological, and social factors can raise a person's risk. Leading eating disorder researcher, Dr. Walter Kaye, sums this up by saying, "Genetics loads the gun, and environment pulls the trigger." (3)

What are the common types of eating disorders?

Eating disorders are diagnosed as mental health disorders, based on the Diagnostic and Statistical Manual of Mental Disorders, which at the time of this publication is the 5th edition (DSM-V). Common eating disorders include **anorexia nervosa**, **bulimia nervosa**, **binge-eating disorder** and **other specified feeding and eating disorders** (though there are others as well). If you or someone you know experiences the symptoms listed below, it could be a sign of an eating disorder—call a health provider right away for help.

What is anorexia nervosa?

People with anorexia nervosa avoid food, severely restrict food, or eat very small quantities of only certain foods. Even when they are dangerously underweight, they may see themselves as overweight. They may also weigh themselves repeatedly.

There are two subtypes of anorexia nervosa: a *restrictive* subtype and *binge-purge* subtype.

Restrictive: People with the restrictive subtype of anorexia nervosa place severe restrictions on the amount and type of food they consume.

Binge-Purge: People with the binge-purge subtype of anorexia nervosa also place severe restrictions on the amount and type of food they consume. In addition, they may have binge eating and purging behaviors (such as vomiting, use of laxatives and diuretics, etc.).

Symptoms include:

- Extremely restricted eating and/or intensive and excessive exercise
- Extreme thinness (emaciation), though not necessarily!
- A relentless pursuit of thinness and unwillingness to maintain a normal or healthy weight
- Intense fear of gaining weight
- Distorted body image, a self-esteem that is heavily influenced by perceptions of body weight and shape, or a denial of the seriousness of low body weight

Over time, these symptoms may also develop:

- Thinning of the bones (osteopenia or osteoporosis)
- Mild anemia and muscle wasting and weakness
- Brittle hair and nails
- Dry and yellowish skin
- Growth of fine hair all over the body (lanugo)
- Severe constipation
- Low blood pressure, slowed breathing and pulse (which may lead to sudden cardiac death)
- Damage to the structure and function of the heart
- Drop-in internal body temperature, causing a person to feel cold all the time
- Lethargy, sluggishness, or feeling tired all the time
- Infertility
- Brain damage and cognitive distortions
- Multi-organ failure

Anorexia can be fatal. Anorexia nervosa has the highest mortality (death) rate of *any* mental disorder. People with anorexia may die from medical conditions and complications associated with starvation or suicide.

What is bulimia nervosa? (2)

People with bulimia nervosa have recurrent episodes of eating unusually large amounts of food and feeling a lack of control over these episodes. This binge-eating is followed by behaviors that compensate for the overeating, such as forced vomiting, excessive use of laxatives or diuretics, fasting, excessive exercise, or a combination of these behaviors. Unlike those with anorexia nervosa, people with bulimia nervosa may maintain a normal weight or be overweight.

Symptoms include:

- Chronically inflamed and sore throat
- Swollen salivary glands in the neck and jaw area
- Worn tooth enamel and increasingly sensitive and decaying teeth (a result of exposure to stomach acid)
- Acid reflux disorder and other gastrointestinal problems
- Intestinal distress and irritation from laxative abuse
- Severe dehydration from purging
- Electrolyte imbalance (too low or too high levels of sodium, calcium, potassium and other minerals), which can lead to stroke or heart attack

What is binge-eating disorder? (2)

People with binge-eating disorder lose control over their eating. Unlike bulimia nervosa, periods of binge-eating are **not** followed by purging, excessive exercise, or fasting. As a result, people with binge-eating disorder are often overweight or obese, though they may be at a normal weight. Binge-eating disorder is the most common eating disorder in the U.S.

Symptoms include:

- Eating unusually large amounts of food in a specific amount of time, such as a 2-hour period
- Eating fast during binge episodes, perhaps even feeling disassociated from their body while doing it
- Eating even when full or not hungry
- Eating until uncomfortably full
- Eating alone or in secret to avoid embarrassment
- Feeling distressed, ashamed, or guilty about eating
- Frequently dieting, possibly without weight loss

What is Other Specified Feeding and Eating Disorders (OSFED)? (4)

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; 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; type-1 diabetics 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.

How are eating disorders treated?

It is important to seek treatment early for eating disorders. People with eating disorders are at higher risk for suicide and medical complications. Some people with eating disorders may also have other mental disorders (such as depression or anxiety) or problems with substance use.(2) Often blood work looks perfectly normal in people with eating disorders until very late in the disorder, making the individual think they are not "that sick."(4)

Treatment plans for eating disorders include psychotherapy, medical care and monitoring, nutritional counseling, medications, or a combination of these approaches. Typical treatment goals include restoring adequate nutrition, bringing weight to a healthy level, reducing excessive exercise, and stopping binge-purge and binge-eating behaviors. Complete recovery is possible.(2)

Treatment plans are tailored to individual needs and may include one or more of the following:(1)

- Individual, group, and/or family psychotherapy by a mental health professional.
- Medical care and monitoring by a medical provider.
- Nutritional counseling by a registered dietitian
- Medications, prescribed by a psychiatrist or medical provider.

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2.6: 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 2.6.4: 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] While 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 2.6.5: 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 labels 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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2.7: 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.

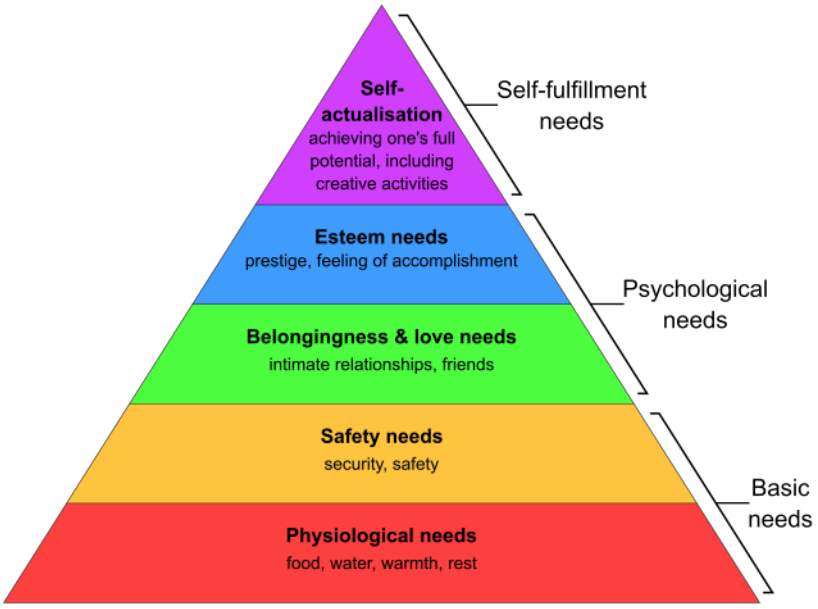


Figure 2.7.1: Maslow's Hierarchy of Needs By Androidmarsexpress - Own work, CC BY-SA 4.0

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

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2.8: 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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3: Nutrition Information



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3.1: 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 3.1.1: 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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3.2: 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.

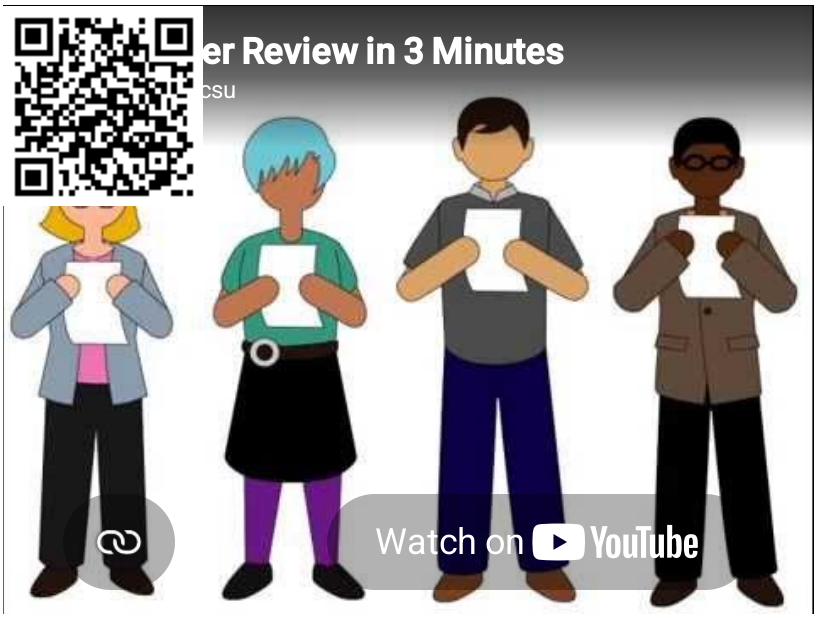
Reporting Scientific Work

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.



VIDEO: "Peer Review in 3 Minutes" by libncsu, YouTube (May 1, 2014), 3:14 minutes.

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3.3: 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.**

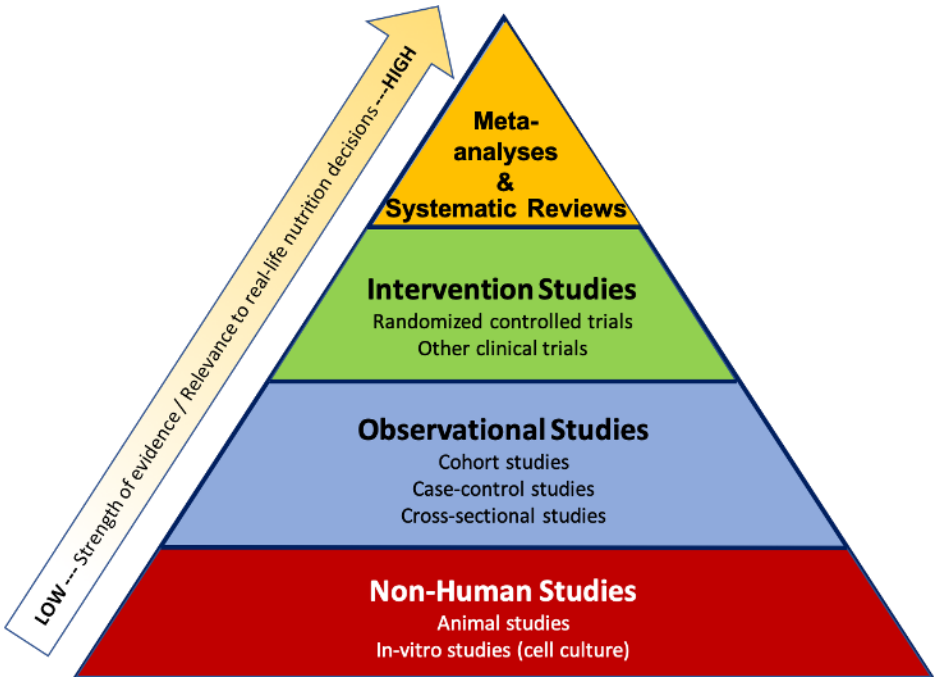


Figure 2.3. The hierarchy of evidence shows types of research studies relative to their strength of evidence and *relevance to real-life nutrition decisions, with the strongest studies at the top and the weakest at the bottom.*

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]

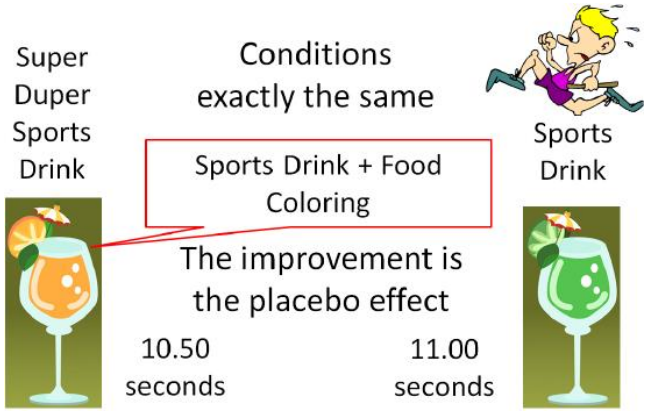


Figure 2.4. An example of the placebo effect

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.)



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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3.4: 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.

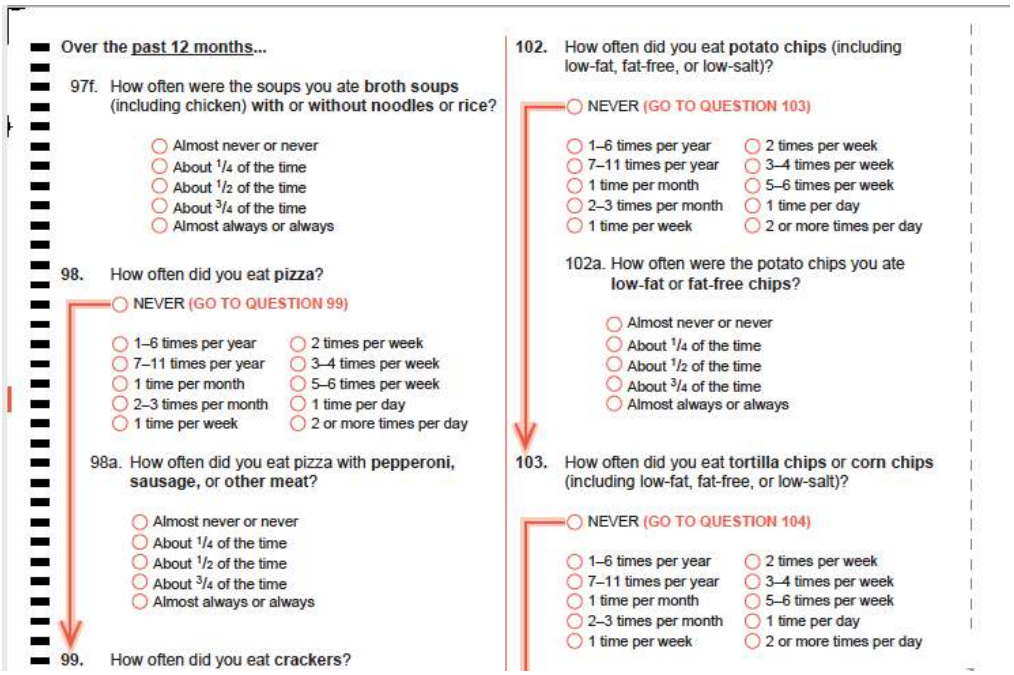
Imagine that you're a nutrition researcher, and you've made the **observation** that over the last 50 years in the U.S., people have been consuming more and more processed foods (foods made with refined ingredients and industrial processes, usually with the addition of sugar, fat, and/or salt). You **hypothesize** 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.

Self-Check:

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3.5: Finding Accurate Sources of Nutrition Information

As we discussed in the previous section, science is always evolving, albeit sometimes slowly. One study is not enough to make a guideline or recommendation or to cure a disease. Science is a stepwise process that continuously builds on past evidence and develops towards a well-accepted consensus, although even that can be questioned as new evidence emerges. Unfortunately, the way scientific findings are communicated to the general public can sometimes be inaccurate or confusing. In today's world, where instant Internet access is just a click away, it's easy to be overwhelmed or misled if you don't know where to go for reliable nutrition information. Therefore, it's important to know how to find accurate sources of nutrition information and how to interpret nutrition-related stories when you see them.



Deciphering Nutrition Information

"New study shows that margarine contributes to arterial plaque."

"Asian study reveals that two cups of coffee per day can have detrimental effects on the nervous system."

How do you react when you read headlines like this? Do you boycott margarine and coffee? When reading nutrition-related claims, articles, websites, or advertisements, always remember that one study neither proves or disproves anything. Readers who may be looking for answers to complex nutrition questions can quickly misconstrue such statements and be led down a path of misinformation, especially if the information is coming from a source that isn't credible. Listed below are ways that you can develop a discerning eye when reading news highlighting nutrition science and research.

- **The scientific study under discussion should be published in a peer-reviewed journal.** Having gone through the peer review process, these studies have been checked by other experts in the field to ensure that their methods and analysis were rigorous and appropriate. Peer-reviewed articles also include a review of previous research findings on the topic of study and examine how their current findings relate to, support, or are in contrast to previous research. Question studies that come from less trustworthy sources (such as non peer-reviewed journals or websites) or that are not formally published.

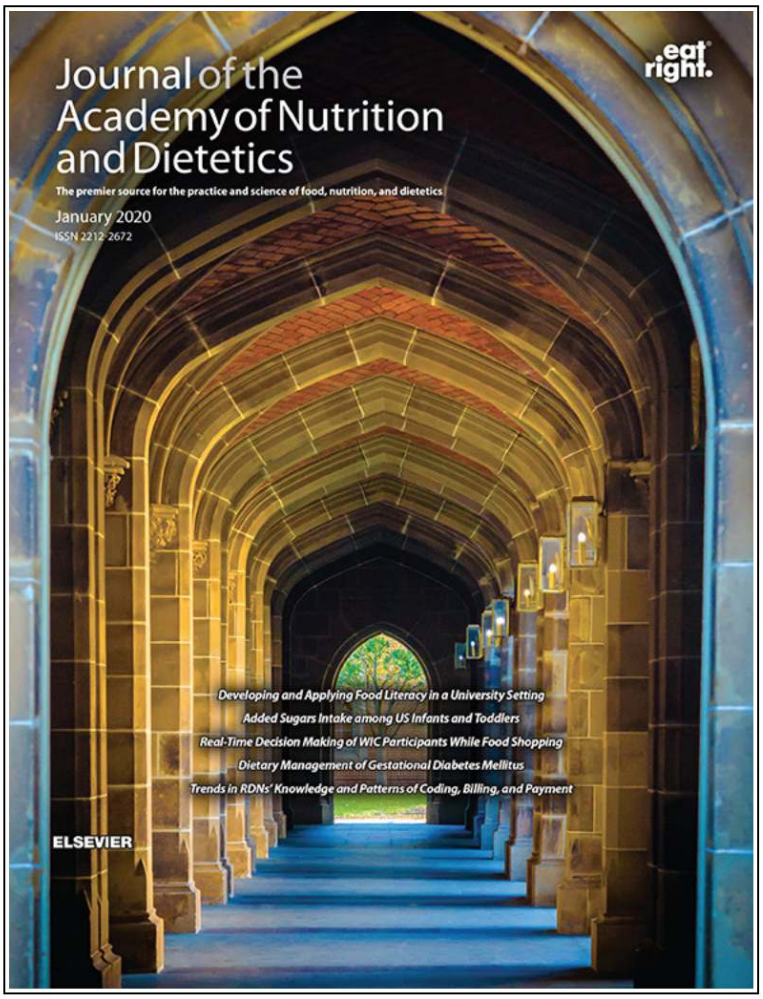


Figure 2.7. An example of a peer-reviewed journal, the Journal of the Academy of Nutrition and Dietetics, which publishes research findings of nutrition scientists. Nutrition research is also frequently published in journals like the Journal of Nutrition, American Journal of Clinical Nutrition, and Journal of Nutrition Education and Behavior, as well as medical and behavioral journals.

- **The report should disclose the methods used by the researcher(s).**
  - Identify the type of study and where it sits on the hierarchy of evidence. Keep in mind that a study in humans is likely more meaningful than one that's in vitro 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.
  - If it's an intervention study, check for some of the attributes of high-quality research already discussed: randomization, placebo control, and blinding. If it's missing any of those, what questions does that raise for you?
  - Did the study last for three weeks or three years? Depending on the research question, studies that are short may not be long enough to establish a true relationship with the issues being examined.
  - Were there ten or two hundred participants? If the study was conducted on only a few participants, it's less likely that the results would be valid for a larger population.
  - What did the participants actually do? It's important to know if the study included conditions that people rarely experience or if the conditions replicated real-life scenarios. For example, a study that claims to find a health benefit of drinking tea but required participants to drink 15 cups per day may have little relevance in the real world.
  - Did the researcher(s) observe the results themselves, or did they rely on self reports from program participants? Self-reported data and results can be easily skewed by participants, either intentionally or by accident.
- **The article should include details on the subjects (or participants) in the study.** Did the study include humans or animals? If human, are any traits/characteristics noted? You may realize you have more in common with certain study participants and can use that as a basis to gauge if the study applies to you.

- **Statistical significance is not the same as real-world significance.** A statistically significant result is likely to have not occurred by chance, but rather to be a real difference. However, this doesn't automatically mean that the difference is relevant in the real world. For example, imagine a study reporting that a new vitamin supplement causes a statistically significant reduction in the duration of the common cold. Colds can be miserable, so that sounds great, right? But what if you look closer and see that the supplement only shortened study subjects' colds by half a day? You might decide that it isn't worth taking a supplement just to shorten a cold by half a day. In other words, it's not a real-world benefit to you.
- **Crediblereports should disseminate new findings in the context of previous research.** A single study on its own gives you very limited information, but if a body of literature (previously published studies) supports a finding, it adds credibility to the study. A news story about a new scientific finding should also include comments from outside experts (people who work in the same field of research but weren't involved in the new study) to provide some context for what the study adds to the field, as well as its limitations.
- **When reading such news, ask yourself, "Is this making sense?"** Even if coffee does adversely affect the nervous system, do you drink enough of it to see any negative effects? Remember, if a headline professes a new remedy for a nutrition-related topic, it may well be a research-supported piece of news, but it could also be a sensationalized story designed to catch the attention of an unsuspecting consumer. Track down the original journal article to see if it really supports the conclusions being drawn in the news report.

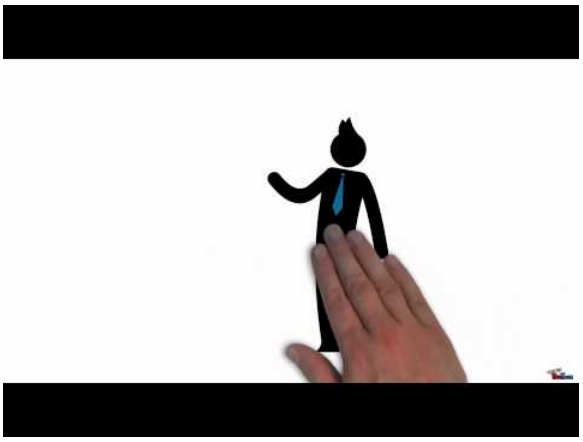
The CRAAPP Test

While there is a wealth of information about nutrition on the internet and in books and magazines, it can be challenging to separate the accurate information from the hype and half-truths. You can use the **CRAAPP Test**[1,2] to help you determine the validity of the resources you encounter and the information they provide. By applying the following principles, you can be confident that the information is credible. We've added several notes to the traditional CRAAPP Test to help you expand your analysis[3] and apply it to nutrition information.

CRAAPP Test Principle	Questions to ask
Currency	When was it written or published? Has the website been updated recently? Do you need current information, or will older sources meet your research need? Where is your topic in the information cycle? Note: In general, newer articles are more likely to provide up-to-date perspectives on nutrition science, so as a starting point, look for those published in the last 5-7 years. However, it depends on the question that you're researching. In some areas, nutrition science hasn't changed much in recent years, or you may be interested in historical background on the question. In either case, an older article would be appropriate.
Relevance	Does it meet stated requirements of your assignment? Does it meet your information needs/answer your research question? Is the information at an appropriate level or for your intended audience?

Authority	Who is the creator/author/publisher/source/sponsor? Are they reputable? What are the author's credentials and their affiliations to groups, organizations, agencies or universities? What type of authority does the creator have? For example, do they have subject expertise (scholar), social position (public office, title), or special experience? Note: The authority on nutrition information would be a registered dietitian nutritionist (RDN), a professional with advanced degree(s) in nutrition (MS or PhD), or a physician with appropriate education and expertise in nutrition. (This will be discussed in more detail on the next page). Look for sources authored or reviewed by experts with this level of authority or written by people who seek out and include their expertise in the article.
Accuracy	Is the information reliable, truthful, and correct? Does the creator cite sources for data or quotations? Who did they cite? Are they cherry-picking facts to support their argument? Is the source peer-reviewed, or reviewed by an editor? Do other sources support the information presented? Are there spelling, grammar, and typo errors that demonstrate inaccuracy? Note: Oftentimes, checking the accuracy of information in a given article or website means opening a new internet tab and doing some additional sleuthing to check the claims against other sources.
Purpose	Is the intent of the website to inform, persuade, entertain, or sell something? Does the point of view seem impartial or biased? Is the content primarily opinion? Is it balanced with other viewpoints? Who is the intended audience? Note: Particularly if you're looking at an organization's website, do some background research on the organization to see who funds it and what is the purpose of the group. That information can help you determine if their point-of-view is likely to be biased.
Process	What kind of effort was put into the creation and delivery of this information? Is it a Tweet? A blog post? A YouTube video? A press release? Was it researched, revised, or reviewed by others before published? How does this format fit your information needs or requirements of assignment?

The CRAAPP Test is a six-letter mnemonic device for evaluating the credibility and validity of information found through various sources, including websites and social media channels. The CRAAPP Test can be particularly useful in evaluating nutrition related news and articles.



VIDEO: "How Library Stuff Works: How to Evaluate Resources (the CRAAP Test)" by McMaster Libraries, YouTube (January 23, 2015), 2:09.

VIDEO: "Evaluating Internet Sources" by Cooperative Library Instruction Project, Lane Community College Library, (July 21, 2015), 7:09.

Red Flags of Junk Science

When it comes to nutrition advice, the adage holds true that "if it sounds too good to be true, it probably is." There are several telltale signs of ***junk science***—untested or unproven claims or ideas usually meant to push an agenda or promote special interests. In addition to using the CRAAPP Test to decipher nutrition information, you can also use these simple guidelines to spot red flags of junk science. When you see one or more of these red flags in an article or resource, it's safe to say you should at least take the information with a grain of salt, if not avoid it altogether.

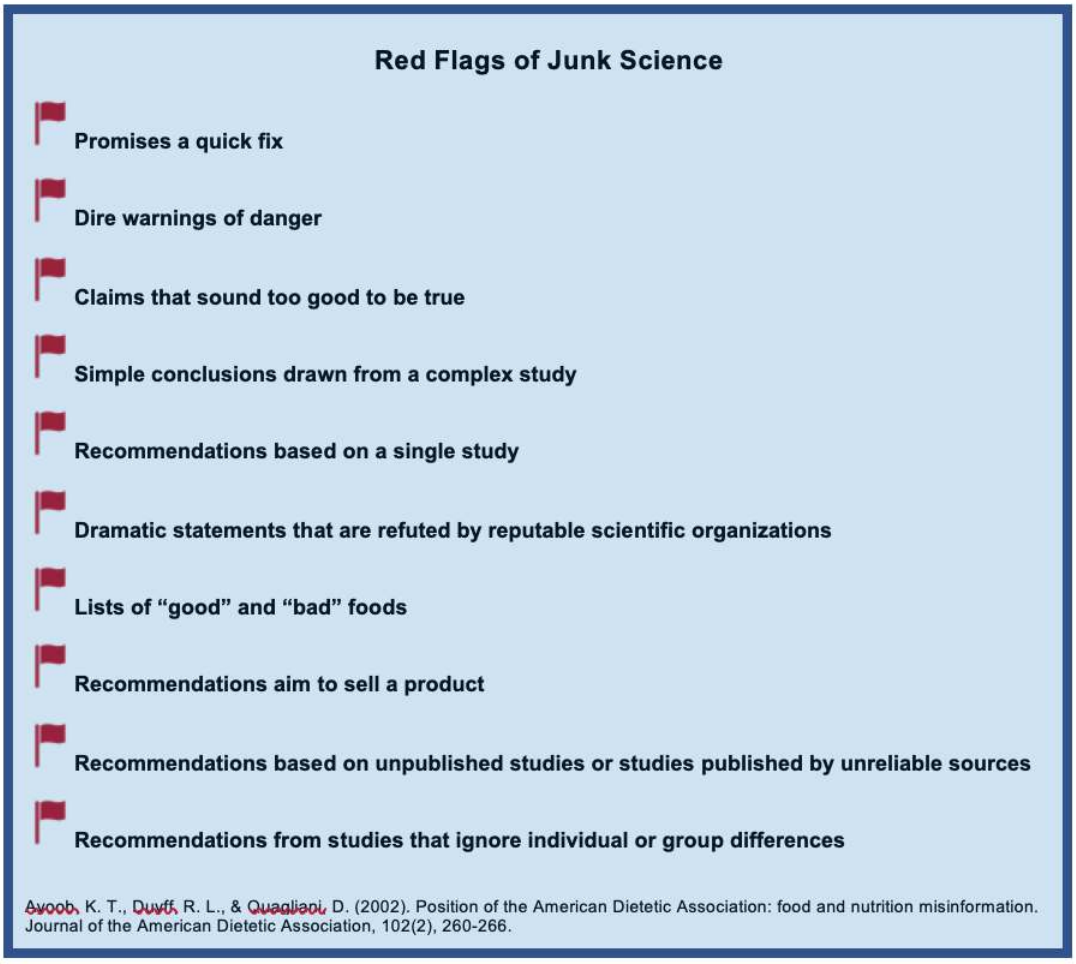


Figure 2.8. The Red Flags of Junk Science were written by the Food and Nutrition Science Alliance, a partnership of professional scientific associations, to help consumers critically evaluate nutrition information.

With the mass quantities of nutrition articles and stories circulating in media outlets each week, it's easy to feel overwhelmed and unsure of what to believe. But by using the tips outlined above, you'll be armed with the tools needed to decipher every story you read and decide for yourself how it applies to your own nutrition and health goals.

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3.6: Who Can You Trust for Nutrition Information?

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:

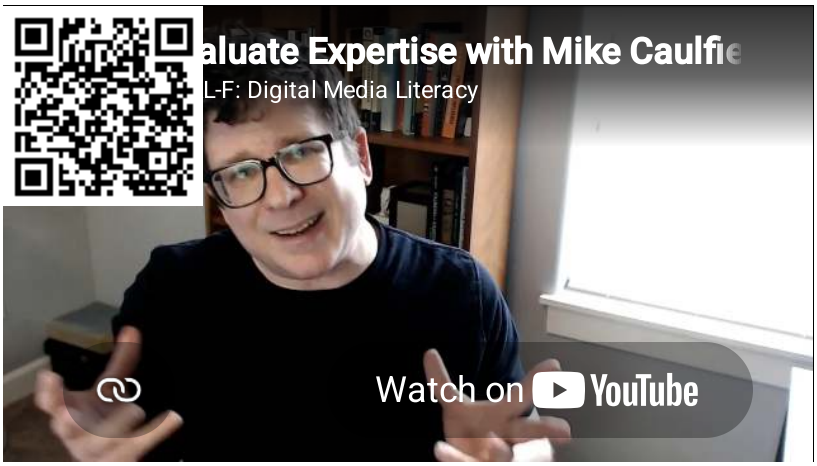
- Registered dietitian nutritionist (RD or RDN)
- Professional with advanced degree(s) (MS or PhD) in nutrition
- Physician (MD) with appropriate education and expertise in nutrition

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.



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:

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3.7: Understanding Food 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 nine major allergens, which include milk, egg, fish, crustacean shellfish, tree nuts, wheat, peanuts, soybeans, and sesame.[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.

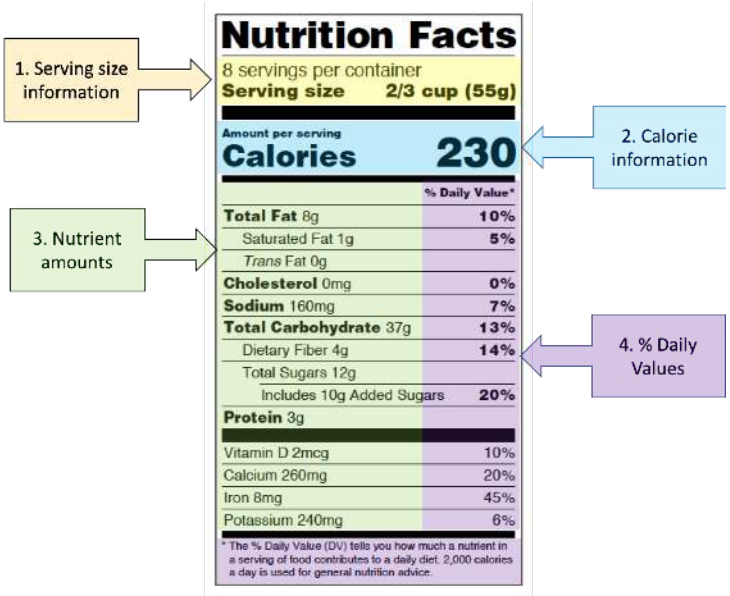


Figure 1.13. The four main sections of a Nutrition Facts label, highlighted in color.

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.

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.



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.

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3.14: Research Highlight - Nutrition Assessments

Introduction

Nutritional assessment is the interpretation of anthropometric, biochemical (laboratory), clinical and dietary data to determine whether a person or groups of people are well nourished or malnourished (overnourished or undernourished).

Nutritional assessment can be done using the ABCD methods. These refer to the following:

- A. Anthropometry
- B. Biochemical methods
- C. Clinical methods
- D. Dietary methods

Anthropometry methods of assessing nutritional status

The word anthropometry comes from two words: Anthropo means ‘human’ and metry means ‘measurement’. The different measurements taken to assess growth and body composition are presented below.

To assess growth, several different measurements including length, height, weight, head circumference, mid-arm circumference, skin-fold thickness, head/chest ratio, and hip/waist ratio can be used. Height and weight measurements are essential in children to evaluate physical growth. As an additional resource, the NHANES Anthropometry Procedures Manual (revised January 2004) can be viewed here https://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/BM.pdf

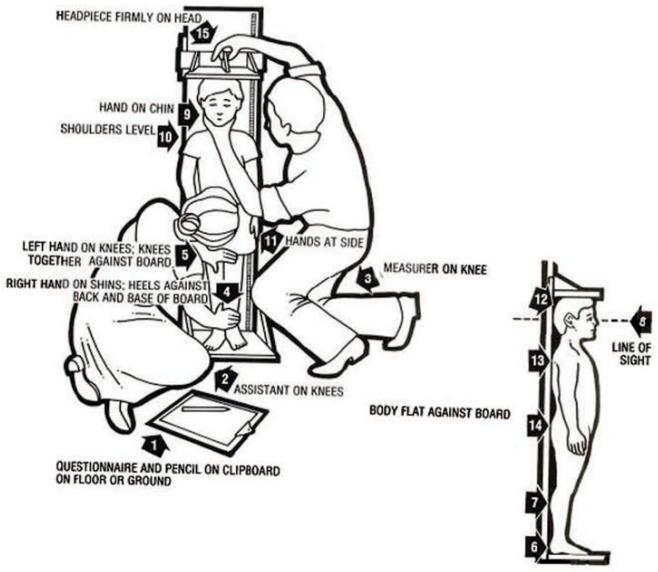


Figure 1.3 Measuring Height. (Source: UNICEF, 1986, How to weigh and measure children: assessing the nutrition status of young children)

Biochemical methods of assessing nutritional status

Biochemical or laboratory methods of assessment include measuring a nutrient or its metabolite in the blood, feces, urine or other tissues that have a relationship with the nutrient. An example of this method would be to take blood samples to measure levels of glucose in the body. This method is useful for determining if an individual has diabetes.



Figure 1.4 Measuring Blood Glucose Levels. Image by TesaPhotography / CC0

Clinical methods of assessing nutritional status

In addition to the anthropometric assessments, you can also assess clinical signs and symptoms that might indicate potential specific nutrient deficiency. Special attention are given to organs such as skin, eyes, tongue, ears, mouth, hair, nails, and gums. Clinical methods of assessing nutritional status involve checking signs of deficiency at specific places on the body or asking the patient whether they have any symptoms that might suggest nutrient deficiency.

Dietary methods of assessing nutritional status

Dietary methods of assessment include looking at past or current intakes of nutrients from food by individuals or a group to determine their nutritional status. There are several methods used to do this:

24 hour recall

A trained professional asks the subject to recall all food and drink consumed in the previous 24 hours. This is a quick and easy method. However, it is dependent upon the subject's short-term memory and may not be very accurate.

Food frequency questionnaire

The subject is given a list of foods and asked to indicate intake per day, per week, and per month. This method is inexpensive and easy to administer. It is more accurate than the 24 hour recall.

Food Diary

Food intake is recorded by the subject at the time of eating. This method is reliable but difficult to maintain. Also known as a food journal or food record.

Observed food consumption

This method requires food to be weighed and exactly calculated. It is very accurate but rarely used because it is time-consuming and expensive.

Evolving Science

Science is always moving forward, albeit sometimes slowly. One study is not enough to make a guideline or a recommendation, or cure a disease. Science is a stepwise process that builds on past evidence and finally culminates into a well-accepted conclusion. Unfortunately, not all scientific conclusions are developed in the interest of human health, and some can be biased. Therefore, it is important to know where a scientific study was conducted and who provided the funding, as this can have an impact on the scientific conclusions being made. For example, an air quality study paid for by a tobacco company diminishes its value in the minds of readers as well as a red meat study performed at a laboratory funded by a national beef association.

Nutritional Science Evolution

One of the newest areas in the realm of nutritional science is the scientific discipline of nutritional genetics, also called nutrigenomics. Genes are part of DNA and contain the genetic information that make up all of our traits. Genes are codes for proteins and when they are turned "on" or "off," they change how the body works. While we know that health is defined as more than just the absence of disease, there are currently very few accurate genetic markers of good health. Rather, there are many more

genetic markers for disease. However, science is evolving, and nutritional genetics aims to identify what nutrients to eat to “turn on” healthy genes and “turn off” genes that cause disease.

Using Science and Technology to Change the Future

As science evolves, so does technology. Both can be used to create a healthy diet, optimize health, and prevent disease. Picture yourself not too far into the future: you are wearing a small “dietary watch” that painlessly samples your blood, and downloads the information to your cell phone, which has an app that evaluates the nutrient profile of your blood and then recommends a snack or dinner menu to assure you maintain adequate nutrient levels. What else is not far off? How about another app that provides a shopping list that adheres to all dietary guidelines and is emailed to the central server at your local grocer, who then delivers the food to your home? The food is then stored in your smart fridge which documents your daily diet at home and delivers your weekly dietary assessment to your home computer. At your computer, you can compare your diet with other diets aimed at weight loss, optimal strength training, reduction in risk for specific diseases or any other health goals you may have. You also may delve into the field of nutritional genetics and download your gene expression profiles to a database that analyzes your genes against millions of others.

References

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CHAPTER OVERVIEW

4: Dietary Recommendations



Figure 4.1: ChooseMyPlate image by U. S. Department of Agriculture / Public Domain

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4.2: Defining Nutrient Requirements- Dietary Reference Intakes
4.3: Dietary Guidelines
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4.7: Diet Analysis - When Enough is Enough

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4.1: 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. Balance
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]

Balance

A **balanced** diet means eating a combination of foods from the different food groups, and because these food groups provide different nutrients, a balanced diet is likely to be adequate in nutrients. 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 is more important than the other. It is the combination of all the different food groups (fruit, vegetables, grains, dairy, protein and fats/oils) that will ensure an adequate diet.



Image 4.1.1: “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.

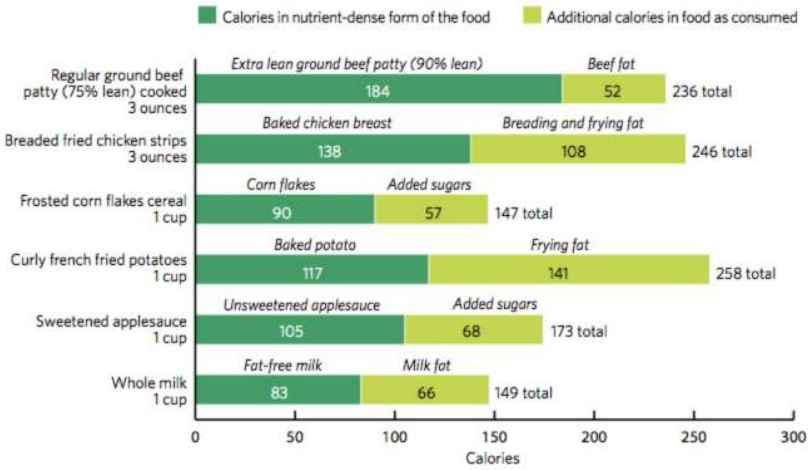


Figure 4.1.1: Examples of the calories found in nutrient-dense food choices compared with calories found in less nutrient-dense forms of these foods. "Examples of the calories in food choices that are not in nutrient dense forms and the calories in nutrient dense forms of these foods" by The Dietary 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 4.1.1: Nutrient-Dense Food Alternatives

Instead of…	Replace with…

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.



Image 4.1.2: "Colours of Health" by Alex Promois is licensed under CC BY-NC 2.0

Variety

Variety refers to consuming different foods within each of the food groups on a regular basis. 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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4.2: 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] 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.

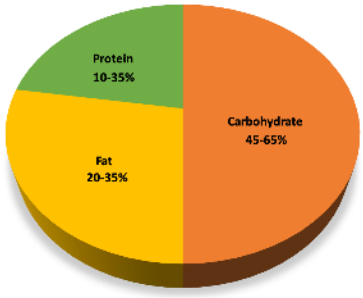


Figure 4.2.1: Acceptable Macronutrient Distribution Ranges (AMDR) for the three energy-yielding macronutrients. "Acceptable Macronutrient Distribution Ranges (AMDR)" by Alice Callahan is licensed under CC BY 4.0.

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 4.2.1: 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.

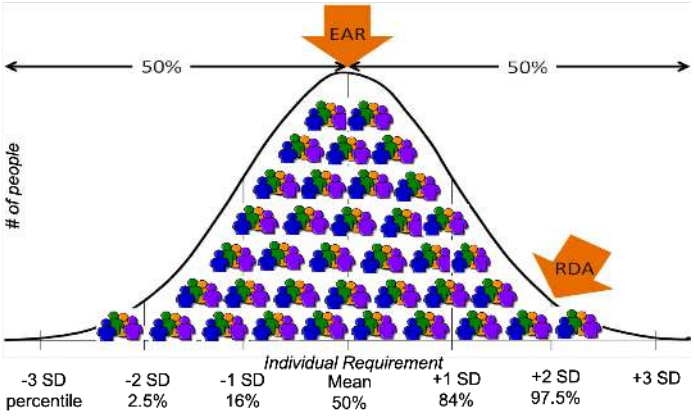


Figure 4.2.2: EAR and RDA relative to individual requirements for a given nutrient.

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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.

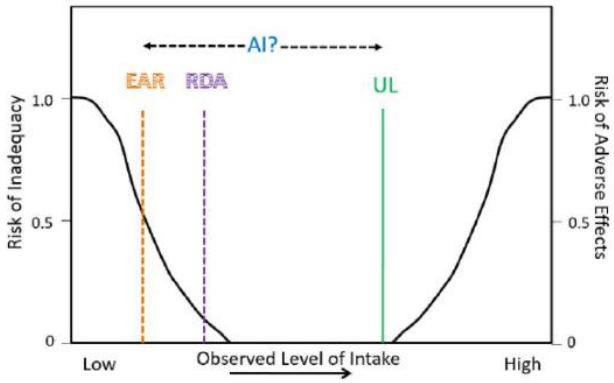
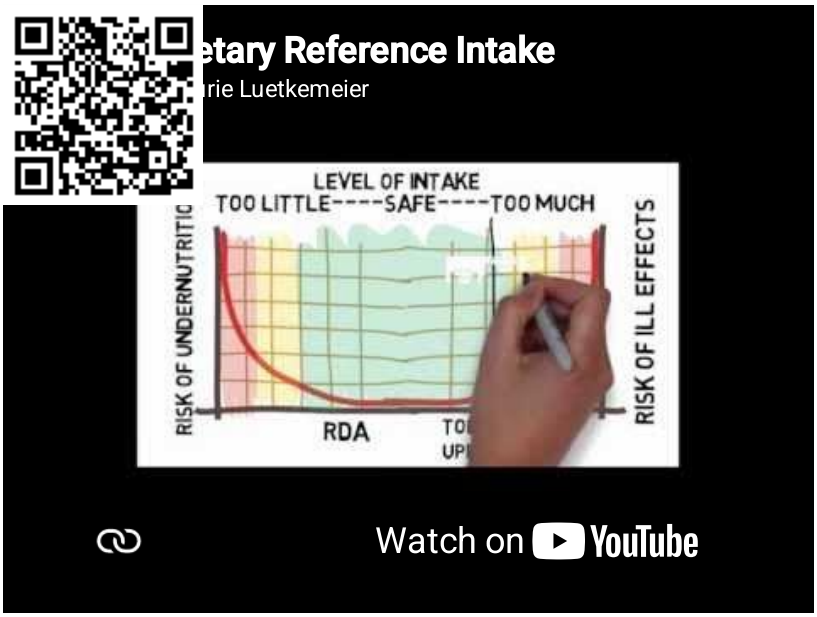


Figure 4.2.3: DRI values for nutrient intake. The EAR, RDA, AI, and UL are shown relative to the observed level of intake and risk of inadequacy and adverse effects. "DRI values for nutrient intake." Kansas State University Human Nutrition Flexbook by Brian Lindshield is licensed under CC BY-NC-SA 4.0

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.



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.

Attributions:

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

References:

- [1] Institute of Medicine, Food and Nutrition Board. (2005). *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Washington, D.C.: The National Academies Press.
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4.3: Dietary Guidelines

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.

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 4.3.1: "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 4.3.2: "Sweedens 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.

One way the USDA and other federal agencies implement the Dietary Guidelines is through MyPlate, which we will discuss next.

MyPlate (USDA Food Guide)

For many years, the U.S. government has been encouraging Americans to develop healthful dietary habits. For example, the food pyramid was introduced in 1992 as the symbol of healthy eating patterns for all Americans.

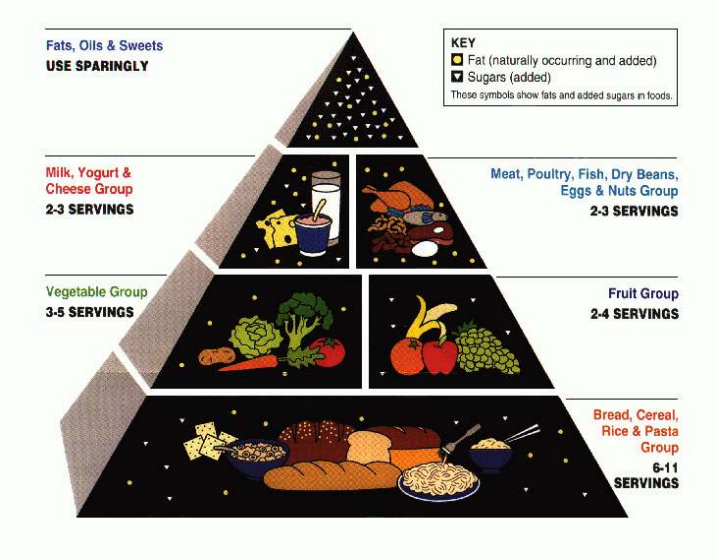


Figure 4.3.3: "The original food pyramid" from the USDA is in the Public Domain

In 2005, the food pyramid was replaced with MyPyramid.

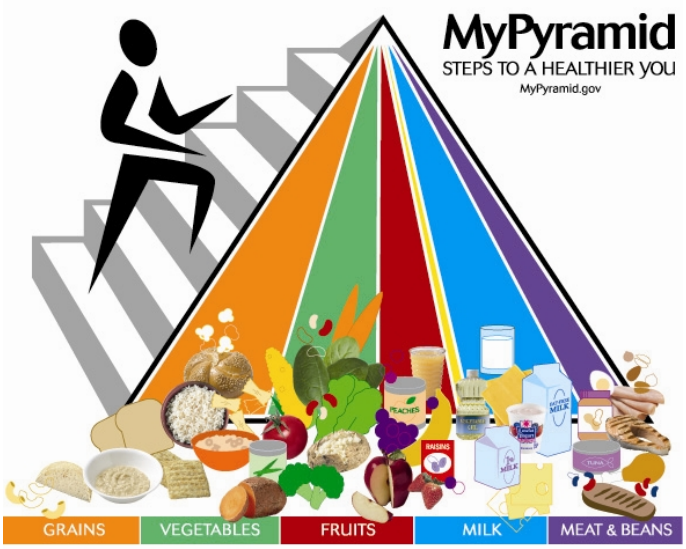


Figure 4.3.4: "Mypyramid" from the USDA is in the Public Domain

MyPyramid, introduced in 2005.

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

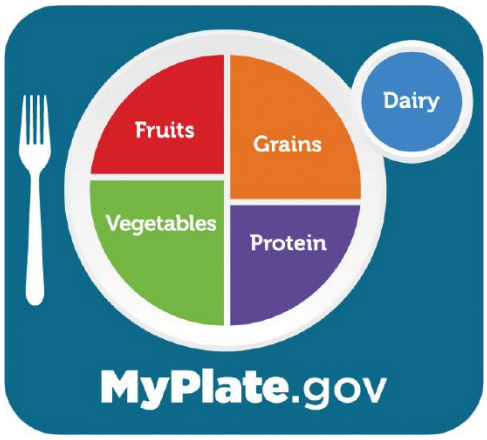


Figure 4.3.5: “MyPlate” from the USDA is in the Public Domain

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 \(\PageIndex{1}\): *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 4.3.6: "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 not difficult:

- **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 4.3.7: "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. Calcium, an important mineral for your body, is also found in lactose-free dairy products and fortified plant-based beverages, like soy milk. You can also get calcium from vegetables and other fortified foods and beverages.
- Oils are also important in your diet as they contain valuable essential fatty acids. **Oils like canola oil also contain more healthful unsaturated fats compared to solid fats like butter.** You can also get oils from whole foods like fish, avocados, and unsalted nuts and seeds. 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 not influenced by political or commercial pressures from food industry lobbyists.

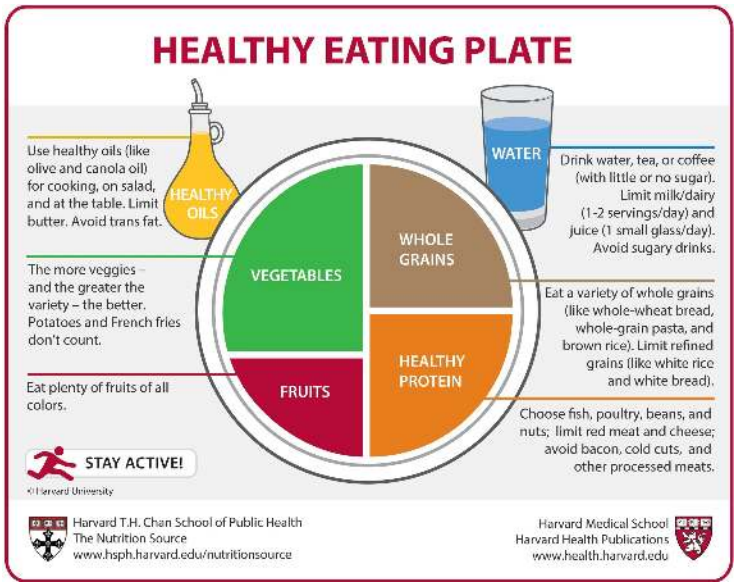


Figure 4.3.8: "Harvard's Healthy Eating Guide" Copyright © 2011, Harvard University. Health, www.thenutritionsource.org, and Harvard Health Publications, www.health.harvard.edu.

The message of the HEP is 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, 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."

Attributions:

- University of Hawai'i at Mānoa Food Science and Human Nutrition Program, "Achieving a Healthy Diet," CC BY-NC 4.0
- "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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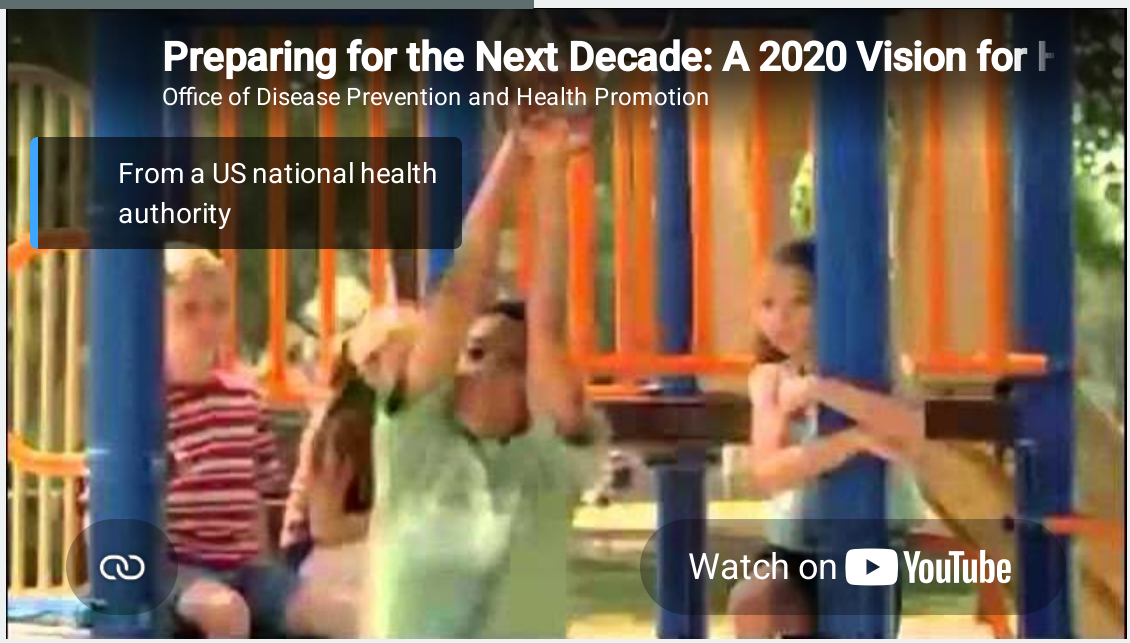
4.4: National Goals for Nutrition and Health- Healthy People 2020

Learning Objectives

- State the Healthy People 2020 nutrition- and weight-status goals.
- List three related objectives for the Healthy People 2020 program.

The Healthy People 2020 program, launched in 2010, is 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 has been 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 will strive 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 4.4.1: Preparing for the Next Decade





"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 4.4.1: 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, 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.

Video 4.4.2: Determinants of Health



Goals for Nutrition and Weight Status

While Healthy People 2020 has many goals and objectives, we are going to focus 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 4.4.2: 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 has 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 has 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 4.4.3: 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 4.4.4: 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.

Video 4.4.3: Active versus Sedentary Lifestyles



This video provides a short overview of leading an active life versus a sedentary life.

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 4.4.5: 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 is 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 are founded upon a determinants of health approach, which means they are 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 are important strategies in achieving the goals of the Healthy People 2020 program.

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4.5: Physical Activity and Lifestyle

Learning Objectives

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



Figure 4.5.1: 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.

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.

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 benefits.
- 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 Centers for Disease Control and Prevention (CDC), excessive alcohol intake causes an estimated seventy-five thousand deaths per year[4]. Staying away from excessive alcohol intake lowers blood pressure, the risk from injury, heart disease, stroke, liver problems, and some types of cancer. While excessive alcohol consumption can be linked to poor health, consuming alcohol in moderation has been found to promote health such as reducing the risk for heart disease and Type 2 diabetes in some people. The United States Department of Health and Human Services (HHS) defines drinking in moderation as no more than one drink a day for women and two drinks a day for men[5].

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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4.6: 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 4.6.1: Rob Knight: How our microbes make us who we are



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4.7: Diet Analysis - When Enough is Enough

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 *2010 Dietary Guidelines* a challenge. In many restaurants and eating establishments, portion sizes have increased, use of SoFAS 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.

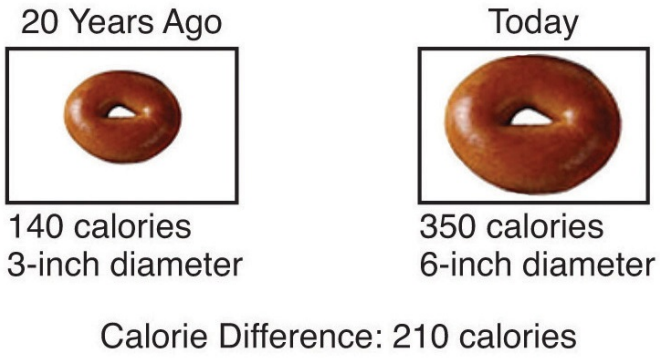


Figure 4.7.1: As food sizes and servings increase it is important to limit the portions of food consumed on a regular basis.

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 4.7.1 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 4.7.1: 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	
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 4.7.1: How Portion Control Can Help You Maintain a Healthy Weight



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 4.7.2: 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			
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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CHAPTER OVERVIEW

5: Digestion, Absorption, and Transport of Nutrients

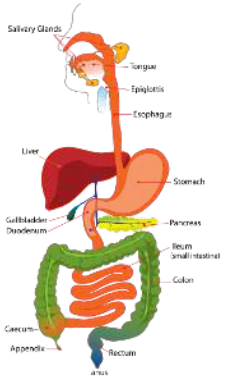


Figure 5.1: Image by Leysi24 / CC BY-SA 3.0

5.1: Human Body Organization
5.2: Parts of the Digestive System
5.3: Digestive System Processes
5.4: Digestive System Regulation
5.5: Digestive Disorders That Can Compromise Health
5.6: Research Highlight - Food Reactions

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5.1: Human Body Organization

Learning Objectives

- Identify the components of a cell.
- Describe the organization of the human body.

Cells

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

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

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

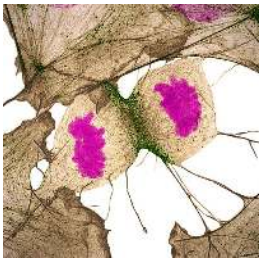


Figure 5.1.1: Human fibroblast undergoing cell division by Nilay Taneja, Vanderbilt University, and Dylan T. Burnette, Ph.D., Vanderbilt University School of Medicine, from National Institute of General Medical Sciences / CC BY-NC-SA 3.0

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

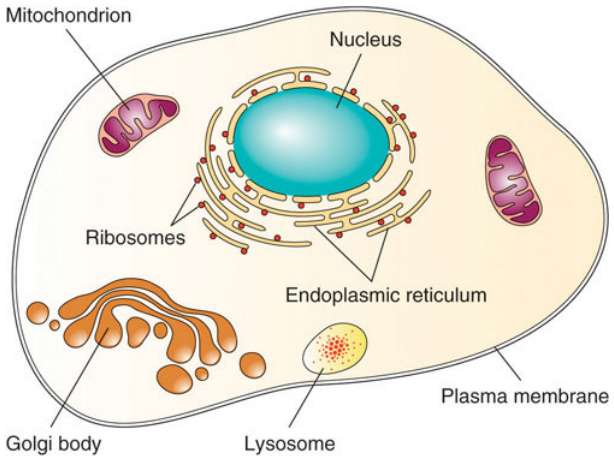


Figure 5.1.1 : The cell is structurally and functionally complex. Image from An Introduction to Nutrition (v. 1.0) by Maureen Zimmerman and Beth Snow / CC BY-NC-SA 3.0

Although we defined the cell as the "most basic" unit of life, it is structurally and functionally complex. A cell can be thought of as a mini-organism consisting of tiny organs called organelles. The organelles are structural and functional units constructed from several macromolecules bonded together. A typical animal cell contains the following organelles: the nucleus (which houses the genetic material DNA), mitochondria (which generate energy), ribosomes (which produce protein), the endoplasmic reticulum (which is a packaging and transport facility), and the Golgi apparatus (which distributes macromolecules). In addition, animal cells contain little digestive pouches, called lysosomes and peroxisomes, which break down macromolecules and destroy foreign invaders. All of the organelles are anchored in the cell's cytoplasm. The cell's organelles are isolated from the surrounding environment by a plasma membrane.

Human Body Organization

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

- **Cells.** Cells are the basic structural and functional unit of all life. Examples include red blood cells and nerve cells.
- **Tissues.** Tissues are groups of cells that share a common structure and function and work together. There are four types of human tissues:
  - connective, which connects tissues;
  - epithelial, which lines and protects organs;
  - muscle, which contracts for movement and support; and
  - nerve, which responds and reacts to signals in the environment.
- **Organs.** Organs are a group of tissues arranged in a specific manner to support a common physiological function. Examples include the brain, liver, and heart.
- **Organ systems.** Organ systems are two or more organs that support a specific physiological function. Examples include the digestive system and central nervous system. There are eleven organ systems in the human body.
- **Organism.** An organism is the complete living system capable of conducting all of life's biological processes.

Table 5.1.1 : The Eleven Organ Systems in the Human Body and Their Major Functions

Organ System	Organ Components	Major Function
Circulatory	heart, blood/lymph vessels, blood, lymph	transport nutrients and waste products
Digestive	mouth, esophagus, stomach, intestines	digestion and absorption
Endocrine	all glands (thyroid, ovaries, pancreas)	produce and release hormones
Lymphatic	white blood cells, lymphatic tissue, marrow	defend against foreign invaders
Integumentary	skin, nails, hair, sweat glands	protective, body temperature regulation

Organ System	Organ Components	Major Function
Muscular	skeletal, smooth, and cardiac muscle	body movement
Nervous	brain, spinal cord, nerves	interprets and responds to stimuli
Reproductive	gonads, genitals	reproduction and sexual characteristics
Respiratory	lungs, nose, mouth, throat, trachea	gas exchange
Skeletal	bones, tendons, ligaments, joints	structure and support
Urinary	kidneys, bladder, ureters	waste excretion, water balance

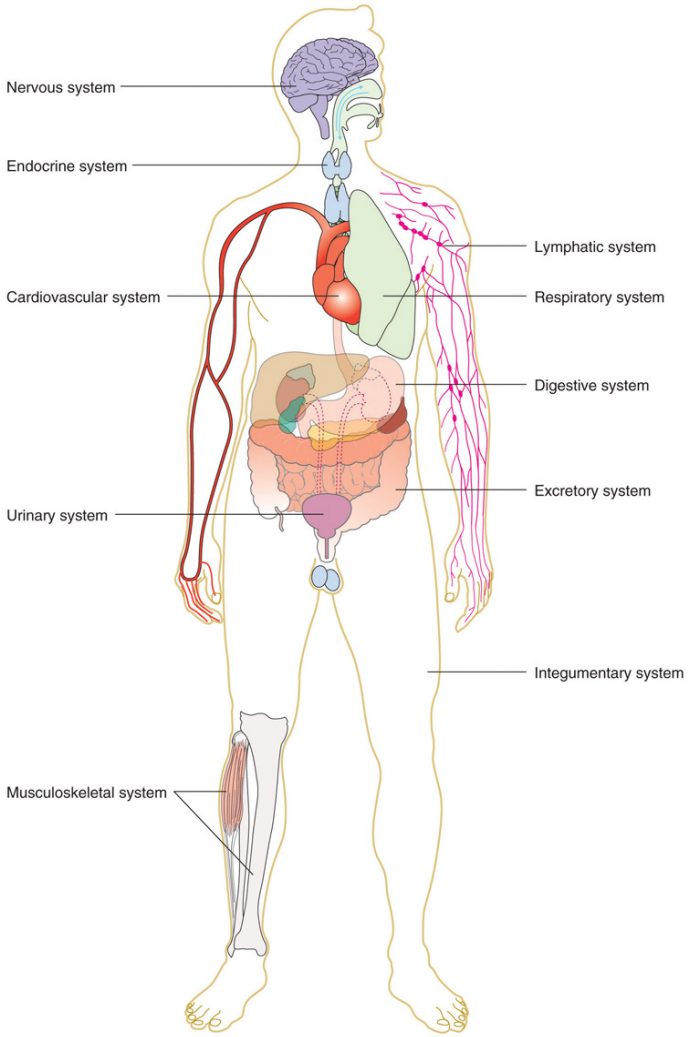


Figure 5.1.2 : Organ Systems in the Human Body © Networkgraphics Image from An Introduction to Nutrition (v. 1.0) by Maureen Zimmerman and Beth Snow / CC BY-NC-SA 3.0

An Organism Requires Energy and Nutrient Input

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

Nutrient and Energy Flow

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

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

Key Takeaways

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

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5.2: 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.

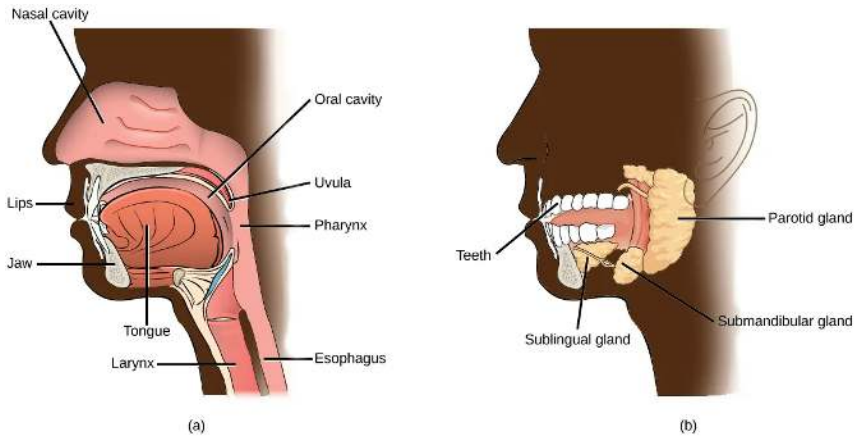


Figure \(\PageIndex{1}\): Digestion of food begins in the (a) oral cavity. Food is masticated by teeth and moistened by saliva secreted from the (b) salivary glands. Enzymes in the saliva begin to digest starches and fats. With the help of the tongue, the resulting bolus is moved into the esophagus by 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.

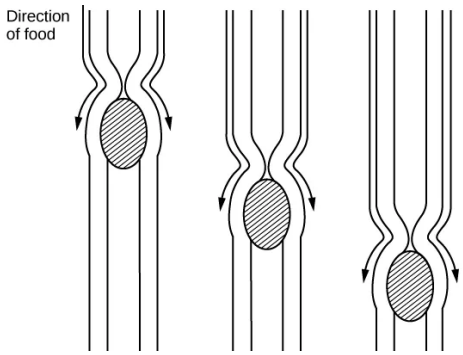


Figure 5.2.2: The esophagus transfers food from the mouth to the stomach through peristaltic movements. Image from Openstax Biology 2e / CC BY 4.0

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.

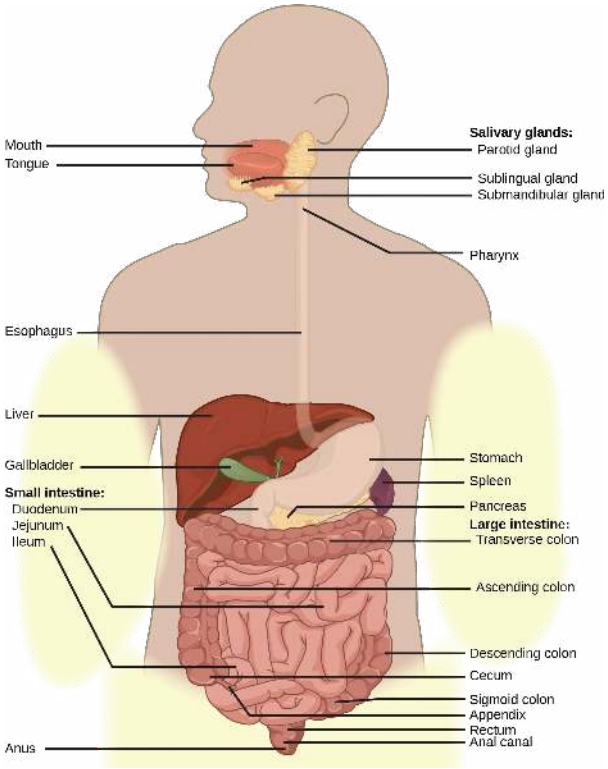


Figure 5.2.3: The human stomach has an extremely acidic environment where most of the protein gets digested. Image from Openstax Biology 2e, modification of work by Mariana Ruiz Villareal / CC BY 4.0

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.

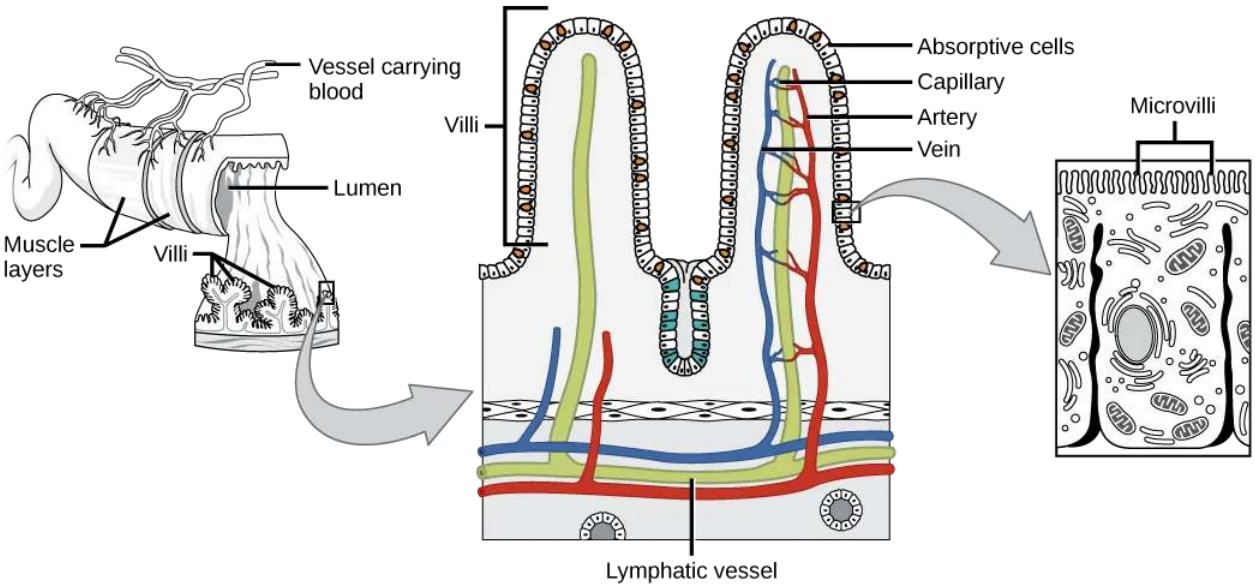


Figure 5.2.4: Villi are folds on the small intestine lining that increase the surface area to facilitate the absorption of nutrients. Image from Openstax Biology 2e / CC BY 4.0

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.

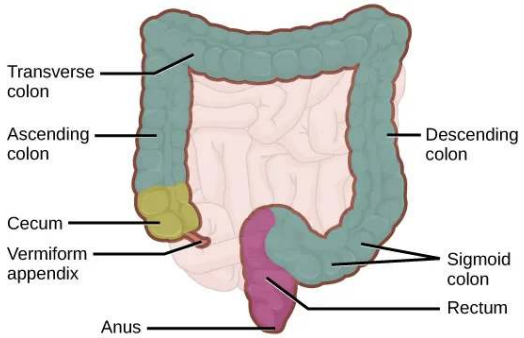


Figure 5.2.5: The large intestine reabsorbs water from undigested food and stores waste material until it is eliminated. Image from Openstax Biology 2e / CC BY 4.0

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

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

Key Takeaways

- The 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

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5.3: 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.

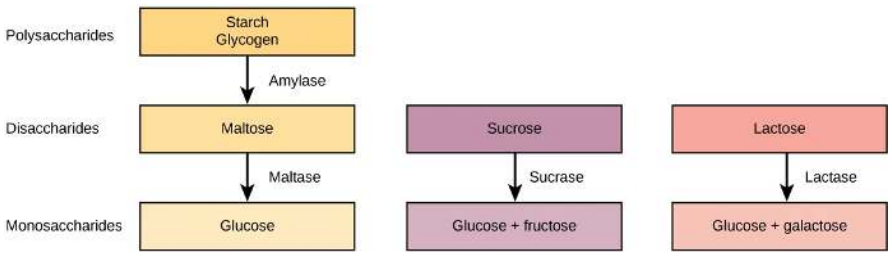
Digestion and Absorption

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

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.

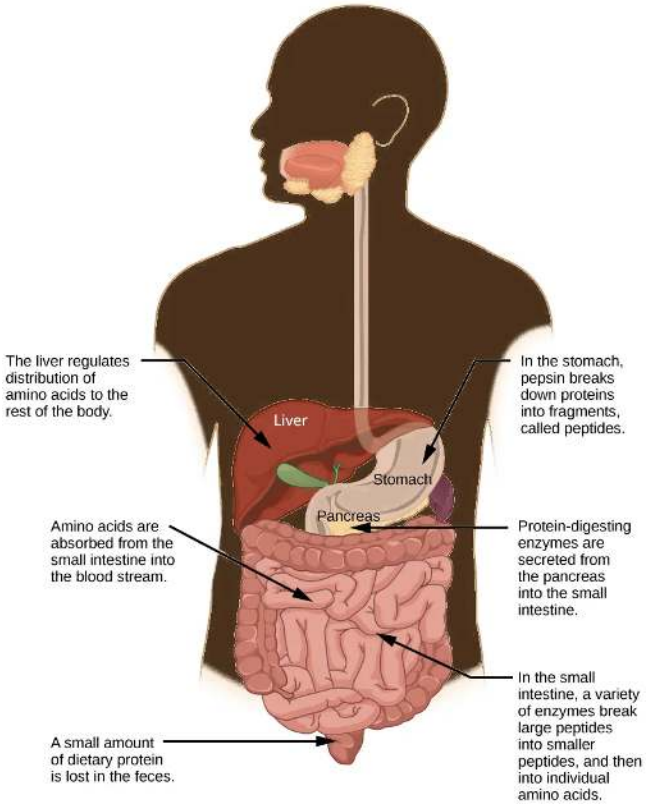


Figure 5.3.2: Protein digestion is a multistep process that begins in the stomach and continues through the intestines. Image from OpenStax Biology 2e / CC BY 4.0

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

Enzyme	Produced By	Site of Action	Substrate Acting On	End Products
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.

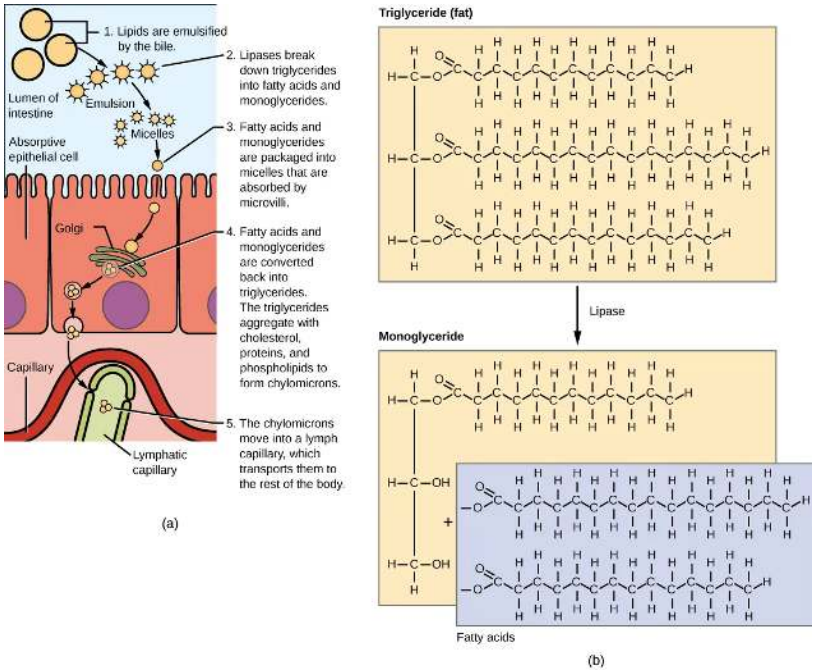


Figure 5.3.3: Lipids are digested and absorbed in the small intestine. Image from OpenStax Biology 2e / CC BY 4.0

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.

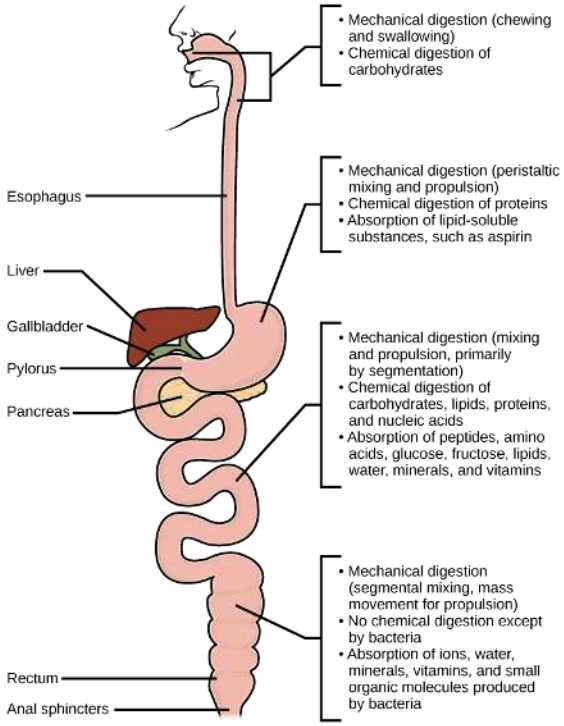


Figure 5.3.4: Mechanical and chemical digestion of food takes place in many steps, beginning in the mouth and ending in the rectum. Image from OpenStax Biology 2e / CC BY 4.0

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.

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5.4: 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 5.4.1: 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.

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5.5: Digestive Disorders That Can Compromise Health

Learning Objectives

- Describe various disorders and diseases related to digestion.

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

Diarrhea

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

Contributing factors

Typical causes of diarrhea include:

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

Treatment

If the diarrhea lasts for a long period of time, a person could become dehydrated if fluids and minerals are not replaced. Fluids and minerals can typically be replaced through normal food and beverage consumption. However, beverages that contain electrolytes (e.g., pedialyte, sports drinks) are also an option.

Constipation

Constipation is generally described as having fewer than 3 bowel movements in a week. In addition, the bowel movements tend to be small, hard, and difficult to pass.

Contributing factors

Factors that contribute to constipation can include:

- travel
- change in diet
- certain medications

Treatment

Common suggestions for relief of constipation include:

- increasing fluid intake
- increasing fiber intake
- regular exercise that incorporates leg movement (e.g., walking)

Gastroesophageal Reflux Disease

Gastroesophageal reflux disease (GERD) is a persistent form of acid reflux that occurs more than two times per week. Acid reflux occurs when the acidic contents of the stomach leak backward into the esophagus and cause irritation. The most common GERD symptom is heartburn, but people with GERD may also experience regurgitation (flow of the stomach's acidic contents into the mouth), frequent coughing, and trouble swallowing.

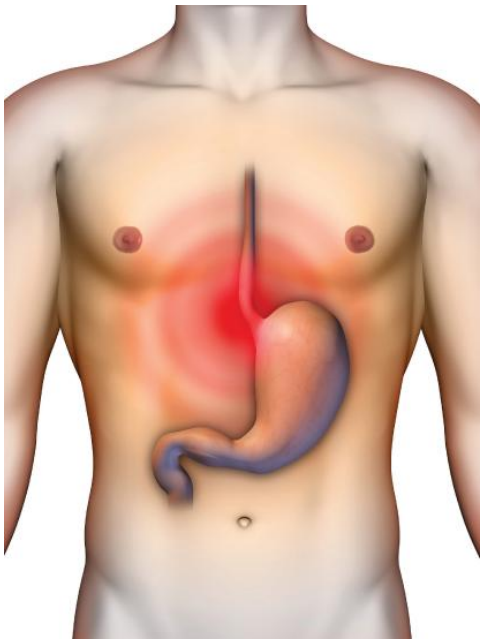


Figure 5.5.1: Heartburn is a burning sensation that radiates throughout the chest. © Shutterstock Image from An Introduction to Nutrition (v. 1.0) by Maureen Zimmerman and Beth Snow / CC BY-NC-SA 3.0

Contributing factors

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

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

Treatment

The first approach to GERD treatment is dietary and lifestyle modifications. Suggestions are to reduce weight if you are overweight or obese, avoid foods that worsen symptoms, eat smaller meals, stop smoking, and remain upright for at least three hours after a meal. There is some evidence that sleeping on a bed with the head raised at least six inches helps lessen the symptoms of GERD.

Many medications are available to treat GERD, including antacids, histamine (H2) blockers, and proton-pump inhibitors. Some evidence from scientific studies indicates that medications used to treat GERD may accentuate certain nutrient deficiencies (e.g., Vitamin B_{12}) in older populations[1]. When these treatment approaches do not work surgery is an option. The most common surgery involves reinforcing the sphincter that serves as a barrier between the stomach and esophagus.

Irritable Bowel Syndrome

Irritable bowel syndrome (IBS) is characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea. Interestingly, IBS produces no permanent structural damage to the large intestine. The disorder is more prevalent in women than men. There is no specific test to diagnose IBS, but other conditions that have similar symptoms (such as celiac disease) must be ruled out. This involves stool tests, blood tests, and having a colonoscopy (which involves the insertion of a flexible tube with a tiny camera on the end through the anus so the doctor can see the colon tissues).

Contributing Factors

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

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

Treatment

As with GERD, the first treatment approaches for IBS are diet and lifestyle modifications. People with IBS are often told to keep a daily food journal to help identify and eliminate foods that cause the most problems. Other recommendations are to eat slower, add more fiber to the diet, drink more water, and/or consider following a low FODMAP diet[2].

Celiac Disease

Celiac disease is an autoimmune disorder caused by an abnormal immune reaction of small intestine cells to a type of protein, called gluten. Gluten is found in grains that are commonly used to make bread, such as wheat, rye, and barley. For those who are sensitive to gluten, it is good to know that corn, millet, buckwheat, and oats do not contain the proteins that make gluten. However, some people who have celiac disease also may have a response to products containing oats. This is most likely the result of cross-contamination of grains during harvest, storage, packaging, and processing.

Symptoms can range from mild to severe and can include pale, fatty, loose stools, gastrointestinal upset, abdominal pain, weight loss and, in children, a failure to grow and thrive. The symptoms can appear in infancy or much later in life, even by age seventy. Celiac disease is not always diagnosed because the symptoms may be mild.

Celiac disease diagnosis requires a blood test and a biopsy of the small intestine. Because celiac disease is an autoimmune disease, antibodies produced by white blood cells circulate in the body and can be detected in the blood. When gluten-containing foods are consumed the antibodies attack cells lining the small intestine leading to a destruction of the small villi projections (see Figure 5.5.2)[3]. This tissue damage can be detected with a biopsy, a procedure that removes a portion of tissue from the damaged organ. Villi destruction is what causes many of the symptoms of celiac disease. The destruction of the absorptive surface of the small intestine also results in the malabsorption of nutrients, so that while people with this disease may eat enough, nutrients do not make it to the bloodstream because absorption is reduced. Over time these nutrient deficiencies can cause health problems. Poor absorption of iron and folic acid can cause anemia, which is a decrease in red blood cells. Anemia impairs oxygen transport to all cells in the body. Calcium and vitamin D deficiences can lead to osteoporosis, a disease in which bones become brittle.

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

Food Intolerances

A food intolerance is gastrointestinal discomfort caused by food. One common food intolerance is lactose intolerance which is caused by the lack of the enzyme lactase. Lactase is produced in the small intestine and is used to break down the sugar in milk called lactose. Without the enzyme present to break down lactose, symptoms such as gas, bloating, cramping, and diarrhea occur. Food intolerances do not involve an immune system response which distinguishes them from food allergies.

Food Allergies

When someone has a food allergy, the immune system mistakenly attacks a certain kind of food (usually the protein component of a food) as if it were a threat. Food allergy symptoms usually develop within a few minutes to two hours after a person has eaten a food to which they are allergic. These symptoms can range from the annoying to the potentially fatal, and include:

- A tingling mouth
- Swelling tongue and/or throat
- Difficulty breathing
- Hives
- Stomach cramps
- Diarrhea
- Vomiting
- Drop in blood pressure
- Loss of consciousness
- Death

There are no clear treatments for food allergies. Epinephrine is sometimes used to control severe reactions; individuals with known and dangerous allergies may get prescriptions for self-injectable devices. The only certain way to avoid allergic reactions to food is

to avoid the foods that cause them. Beyond avoidance, this can mean reading food labels carefully, or even calling manufacturers for product information.

Most food allergies are caused by these nine foods[3]:

1. Milk
2. Eggs
3. Peanuts
4. Tree nuts
5. Fish
6. Shellfish
7. Wheat
8. Soy
9. Sesame

Key Takeaways

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

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5.6: Research Highlight - Food Reactions

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... In the following publication... 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

APA citation

Further evaluation

To evaluate this publication further, it might help to...

References

1.

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CHAPTER OVERVIEW

6: Carbohydrates

6.1: Introduction to Carbohydrates
6.2: Types of Carbohydrates
6.3: Carbohydrate Food Sources and Guidelines for Intake
6.4: Digestion and Absorption of Carbohydrates
6.5: Glucose Regulation and Utilization in the Body
6.6: Fiber - Types, Food Sources, Health Benefits, and Whole vs. Refined Grains
6.7: Sugar- Food Sources, Health Implications, Intakes, and Label-Reading to Identify Sugar
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6.9: Research Highlight - Glycemic Index

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6.1: 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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6.2: 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.

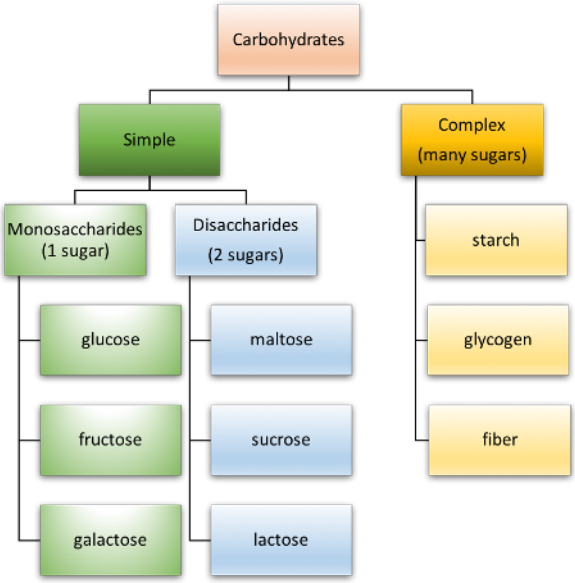


Figure 6.2.1: Carbohydrates can be divided into two main types: simple (including monosaccharides and disaccharides) and complex.

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.

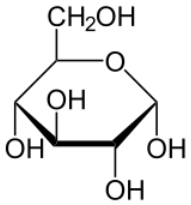
There are 3 monosaccharides:

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***:



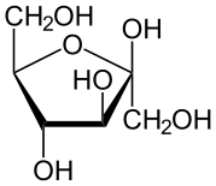
You're already familiar with glucose, because it's the main product of photosynthesis. Plants make glucose as a way of storing the sun's energy in a form that it can use for growth and reproduction.

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!

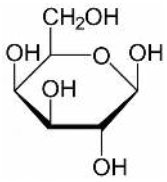


Figure 6.2.2: Fructose in nature: A bee collects sweet nectar from a flower, in the process spreading pollen from flower to flower and helping plants to reproduce. Bees use nectar to make honey, which humans harvest for use as a sweetener. (Honey contains a mix of sucrose, fructose, and glucose). A kiwi 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.

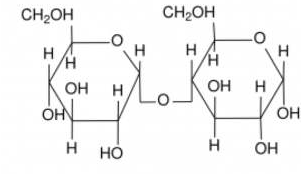
The second type of simple carbohydrates is ***disaccharides***. They contain two sugar units bonded together.

There are 3 disaccharides:

1. **Maltose (glucose + glucose)**
2. **Sucrose (glucose + fructose)**
3. **Lactose (glucose + galactose)**

Maltose

Here is the chemical structure of ***maltose***:



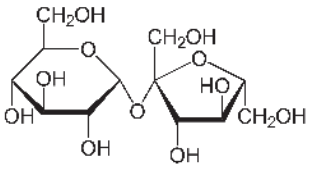
Maltose is made of **two glucose molecules** bonded together. **It doesn't occur naturally in any appreciable amount in foods, with one exception: sprouted grains**. Grains contain a lot of starch, which is made of long chains of glucose (more on this in a minute), and when the seed of a grain starts 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***:

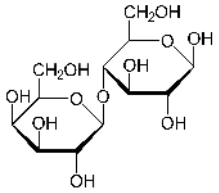


Sucrose is made of a **glucose molecule** bonded to a **fructose molecule**. It's made by plants for the same reason as fructose — to attract animals to eat it and thereby spread the seeds.

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:

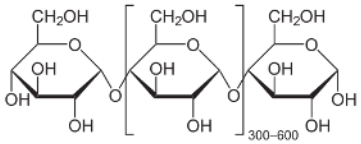
1. Starch
2. Glycogen
3. Fiber

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.

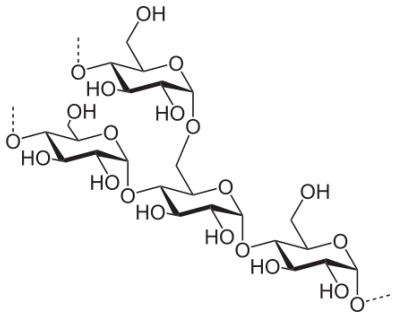
Starch

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.

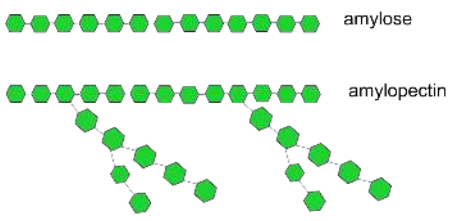
Here is an amylose segment containing 3 glucose units.



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.

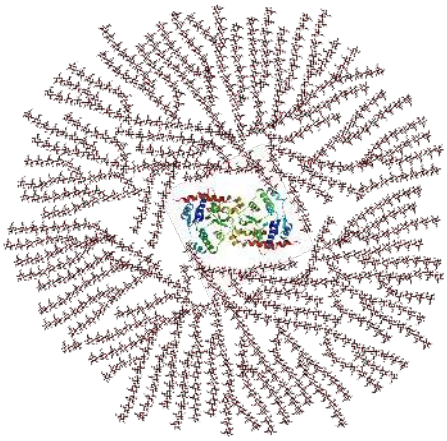


Figure 6.2.3: Glycogen is made from long, branching chains of glucose, radiating around a central protein.

Fiber

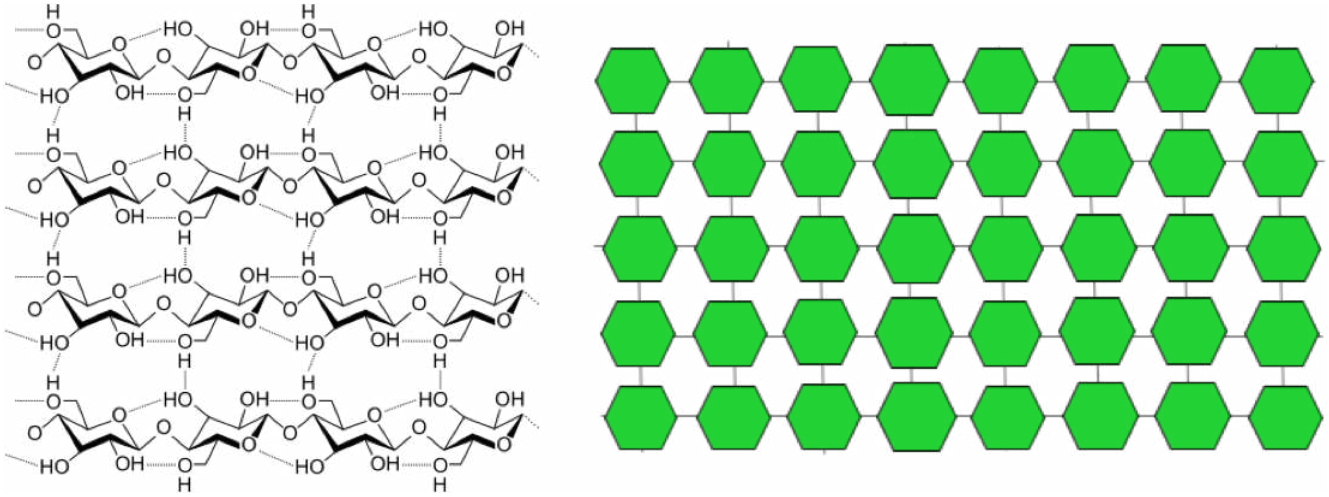
Fiber includes carbohydrates and other structural substances in plants that are indigestible to human enzymes. Fiber is made by plants to provide protection and structural support. Think about thick stems that help a plant stand upright, tough seed husks, and fruit skin that protect what's growing inside. These are full of fiber.



Figure 6.2.4: 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.



Video 6.2.1: "How do carbohydrates impact your health?" - Richard J. Wood, at TED-Ed

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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- " Lactose (simplified structure)" by NEUROtiker is in the Public Domain, CC0

- Figure 4.5. “Flower with bee” by pontla; “Honey” by sunny mama; “Kiwi” by ereta ekarafi; all licensed under CC BY-NC-ND 2.0
- Figure 4.6. “Glycogen” by Häggström, Mikael (2014). “Medical gallery of Mikael Häggström 2014“. *WikiJournal of Medicine***1** (2). DOI:10.15347/wjm/2014.008. ISSN2002-4436. Public Domain.
- Figure 4.7. “Wheat” by Bernat Caser; “Broccoli” by albedo20; “Apple” by Fiona Shields; all licensed under CC BY-NC-ND 2.0
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6.3: 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.

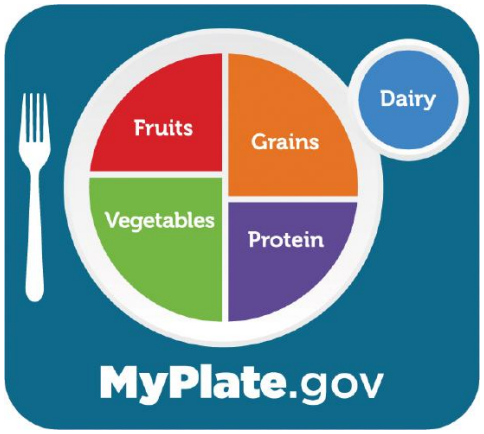


Figure 6.3.1: MyPlate graphic illustrating the USDA food groups: fruits, vegetables, grains, protein and dairy.

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 6.3.1: 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 2020 Dietary Guidelines recommend that less than 10% of total calories come from added sugars starting at age 2, and avoiding foods and beverages with added sugars for infants and children younger than 2, because of its link to obesity and chronic disease. This means that an adult 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 for Carbohydrate	
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 6.3.2: Dietary Recommendations for Carbohydrates

Resources:

- 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/Dietary_Guidelines_for_Americans_2020-2025.pdf
- 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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6.4: 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.

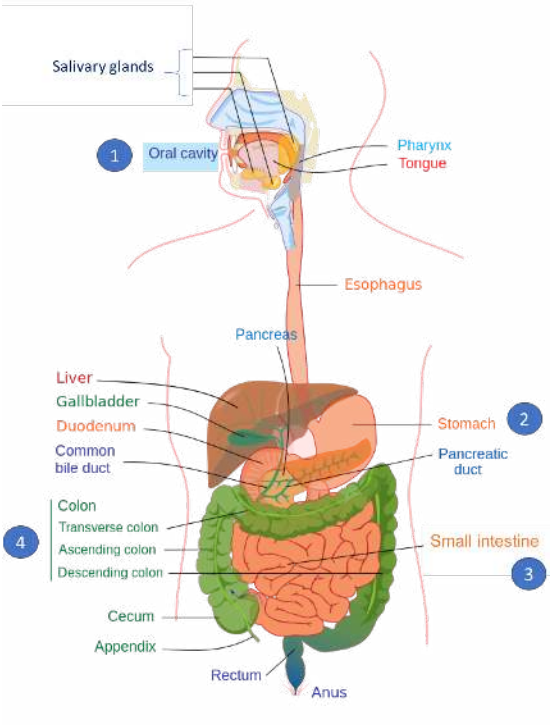


Figure 6.4.1: The digestive system (Copyright; author via source)

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.)

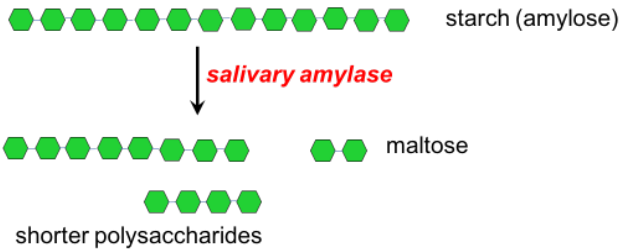


Figure 6.4.2: The enzyme salivary amylase breaks starch into smaller polysaccharides and maltose. (Copyright; author via source)

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.

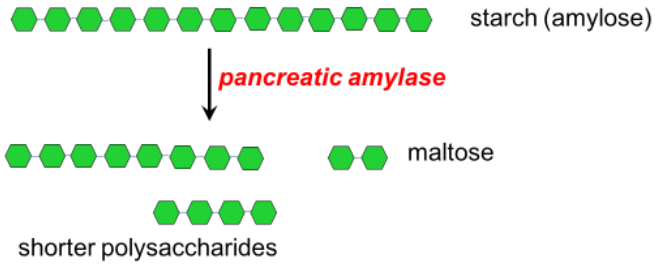
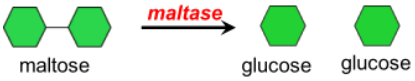


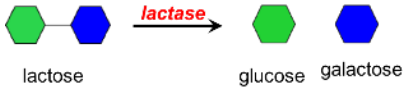
Figure 6.4.3: The enzyme pancreatic amylase breaks starch into smaller polysaccharides and maltose. (Copyright; author via source)

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.

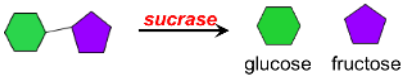


Figure 6.4.4: Action of the enzymes maltase, lactase, and sucrase.

(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.*)

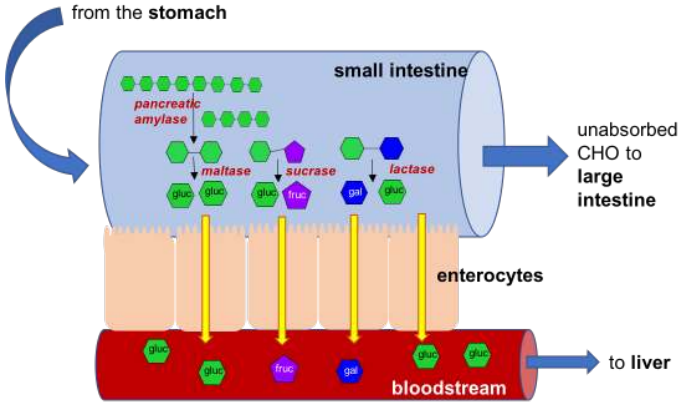


Figure 6.4.5: Digestion and absorption of carbohydrates in the small intestine.

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 6.4.1: *Summary of enzymatic digestion of carbohydrates*



Video 6.4.1: "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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6.5: 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.

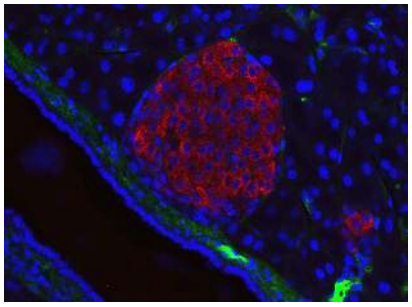


Figure 6.5.1: A mouse islet of Langerhans, visualized with immunofluorescent microscopy. In this image, cell nuclei are stained blue, insulin is stained red, and blood vessels are stained green. You can see that this islet is packed with insulin and sits right next to a blood vessel, so that it can secrete 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!

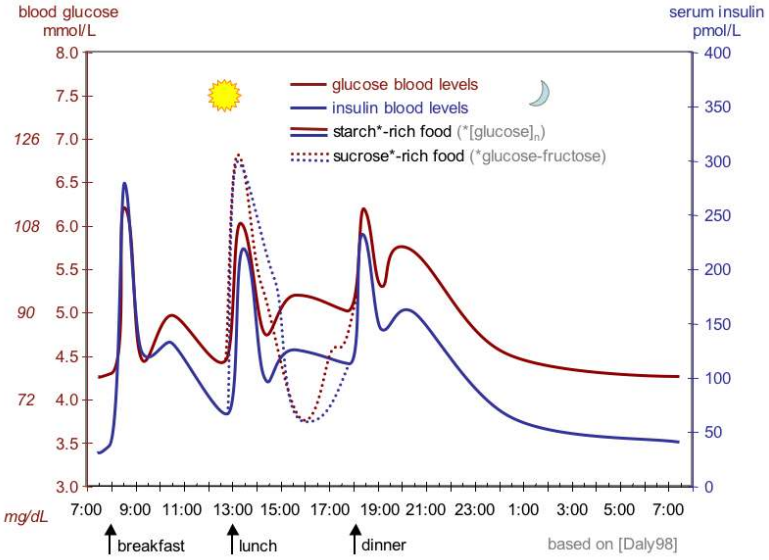


Figure 6.5.2: Typical pattern of blood glucose and insulin during a 24-hour period, showing peaks for each of 3 meals and highlighting the effects of consumption of sugar-rich foods.

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 6.5.3), 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.

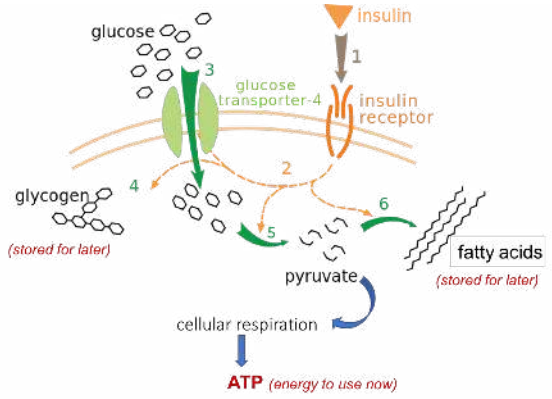


Figure 6.5.3: Insulin binds to its receptors on the cell membrane, triggering GLUT-4 glucose transporters to open on the membrane. This allows glucose to enter the cell, where it can be used in several ways.

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.

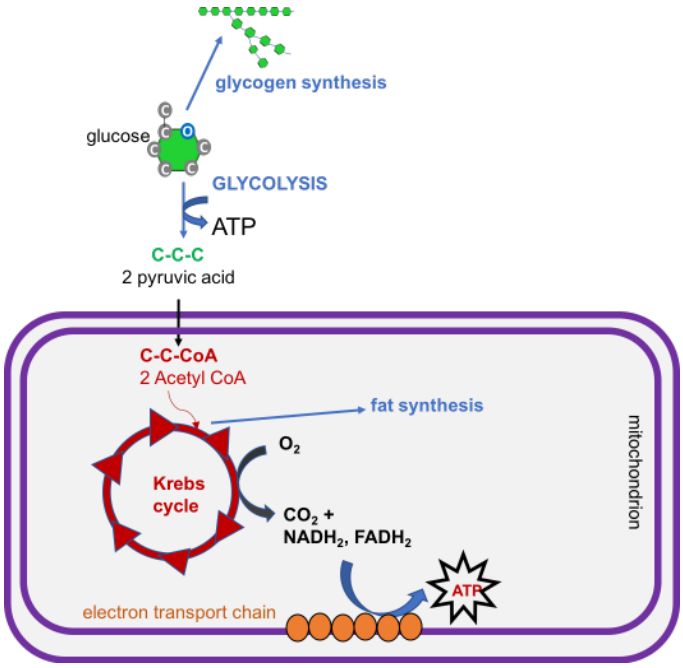


Figure 6.5.4: Overview of glucose metabolism in the fed state, when there is adequate glucose available. Glucose can be used to generate ATP for energy, or it can be stored in the form of glycogen or converted to fat for storage in adipose tissue.

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:

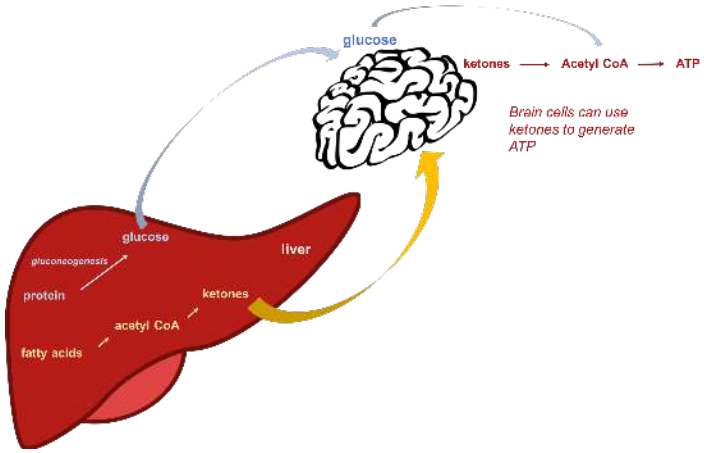
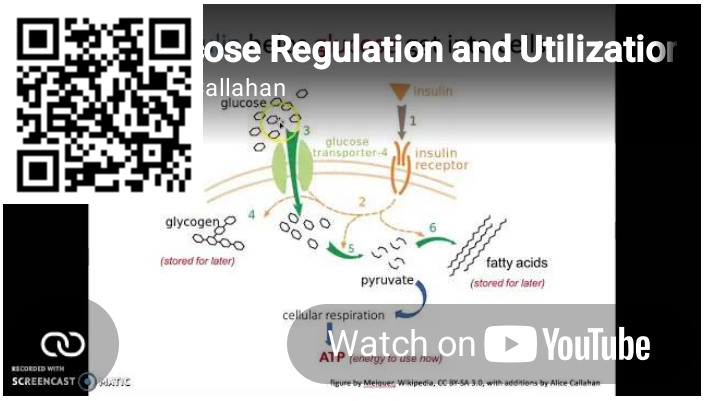


Figure 6.5.5: During starvation or when consuming a low-carbohydrate diet, protein (amino acids) can be used to make glucose by gluconeogenesis, and fats can be used to make ketones in the liver. The brain can adapt to using ketones as an energy source in order to conserve protein and prevent muscle 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.



Video 6.5.1: "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.

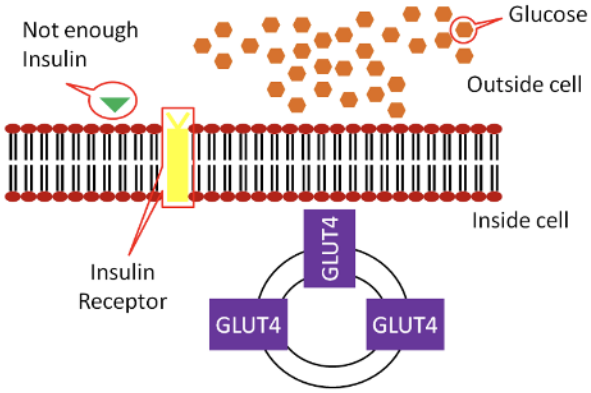


Figure 6.5.6: In type 1 diabetes, the pancreas does not make enough insulin, so glucose transporters (GLUT-4) do not open on the cell membrane, and glucose is stuck outside the cell.

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.



Video 6.5.2: "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.

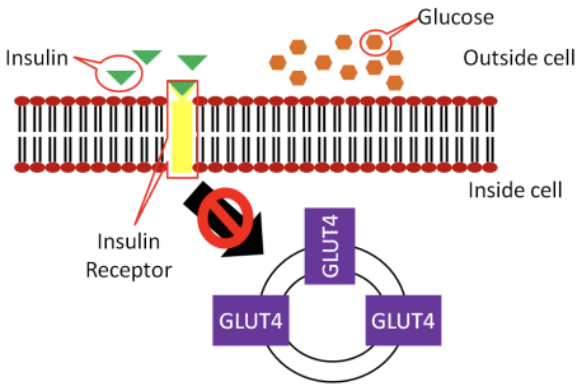


Figure 6.5.7: In type 2 diabetes, the cell does not respond appropriately to insulin, so glucose is stuck outside the cell.

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.

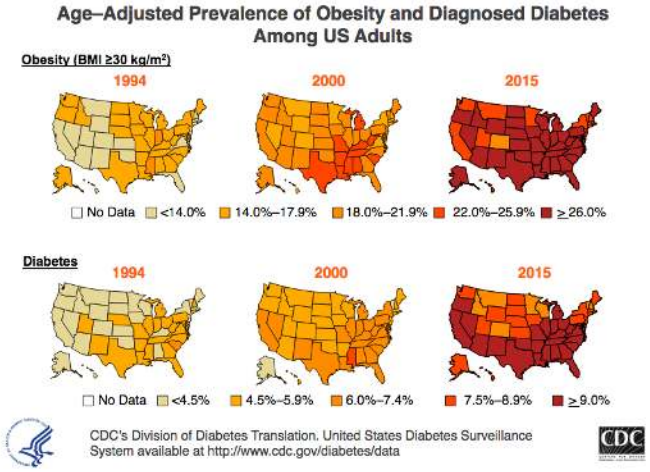
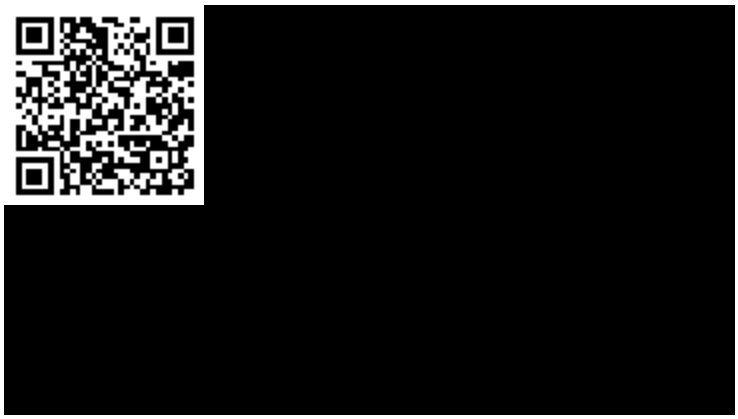


Figure 6.5.8: Data from the CDC show the increasingly prevalence of both obesity and type 2 diabetes between 1994 and 2015.

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.



Video 6.5.3: "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.

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]



Video 6.5.4: "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.

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6.6: 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.

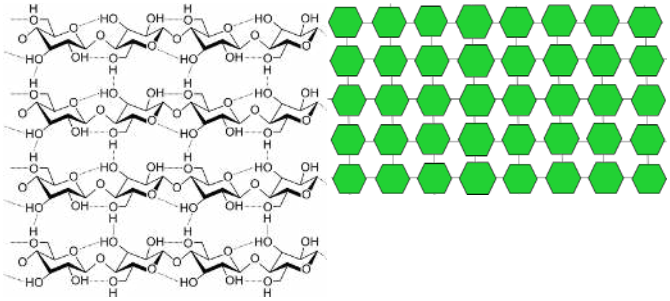


Figure 6.6.1: "Chemical structure of cellulose" by laghi.l is licensed under CC BY-SA 3.0

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 6.6.2: "Bowl of oatmeal" by Rusvaplauke is licensed under CC BY-NC-ND 2.0

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 6.6.1: “Common foods listed with standard portion size, and calories and fiber in a standard portion” by Tamberly Powell is licensed under CC BY-NC-SA 4.0 ; values in table from USDA National Nutrient Database are in the Public Domain

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 6.6.2: "Grain" by rethought is licensed under CC BY-NC 2.0

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.

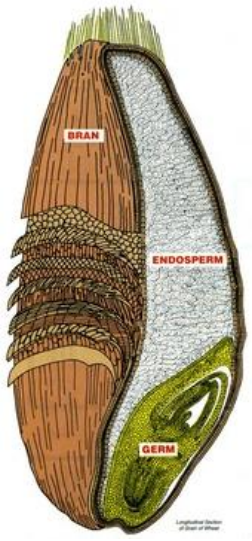


Figure 6.6.3: "Wheat kernel" by Phuthinh Co is licensed under CC BY-SA 2.0

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.

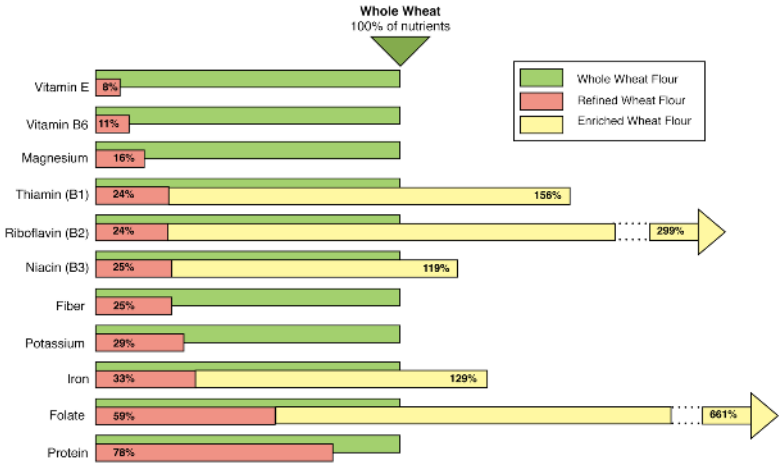


Figure 6.6.4: "Chart comparing nutrient content of whole wheat flour, refined flour and enriched wheat flour" permission for use was given by "Oldways Whole Grains Council"

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:

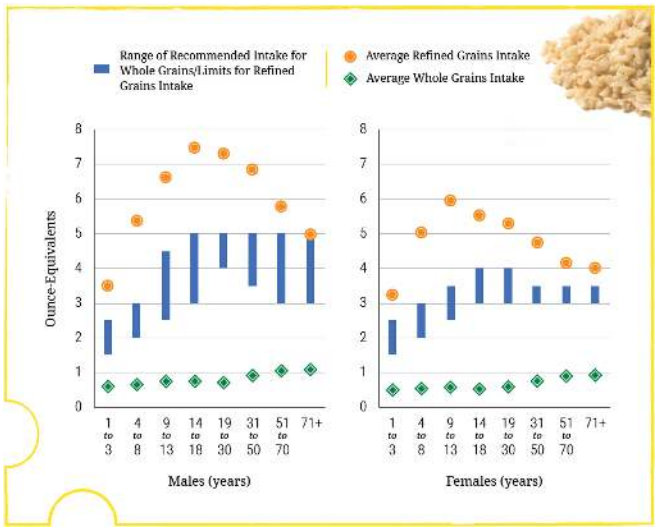


Figure 6.6.5: "Whole grain intake graphic" by Dietary Guidelines for Americans, Figure 2-5 is in the Public Domain

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.

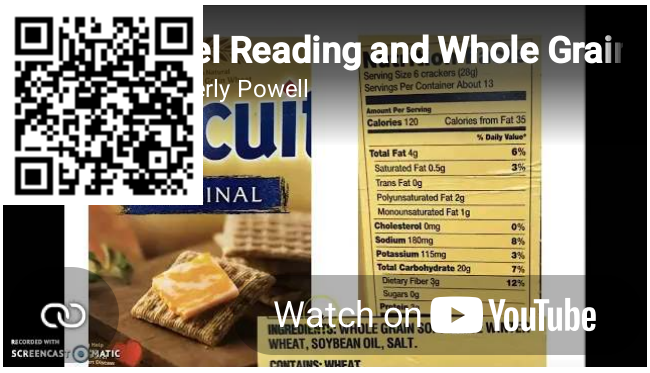
Getting familiar with the name of whole grains will help you identify them. Common varieties include wheat, barley, brown rice, buckwheat, corn, rye, oats, and wild rice. Less known varieties include teff, amaranth, millet, quinoa, black rice, black barley, and spelt.

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 6.6.6: “100% whole wheat bread and label photos” by Tamberly Powell is licensed under CC BY-NC-SA 4.0



Video 6.6.1: “Label Reading and Whole Grains” by Tamberly Powell, YouTube (September 24, 2018), 7:46 minutes.

References:

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6.7: 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 6.7.1: Examples of food that contain naturally occuring sugars: fruit, vegetables, and dairy. "Fruit" by Allen Gottfried is licensed under CC BY-SA 2.0; "vegetables" by johnbillu is licensed under CC BY-NC-ND 2.0; "Cheese" by Finite Focus is licensed under CC BY-NC 2.0

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.

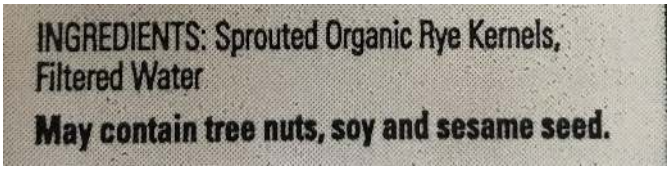


Figure 6.7.2: An example of a sprouted wheat bread that contains naturally occuring maltose from sprouted rye kernels. "Sprouted bread and label" by Tamberly Powell is licensed under CC BY-NC-SA 4.0

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 6.7.3: "61 Names for Added Sugar" by Alice Callahan is licensed under CC BY-NC-SA 4.0. Source for list of sugars: SugarScience, "Hidden in Plain Sight," University of California, San Franscisco, http://sugarscience.ucsf.edu/hidden-in-plain-sight/#.W5li71Inbq0, accessed September 12, 2018.

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.

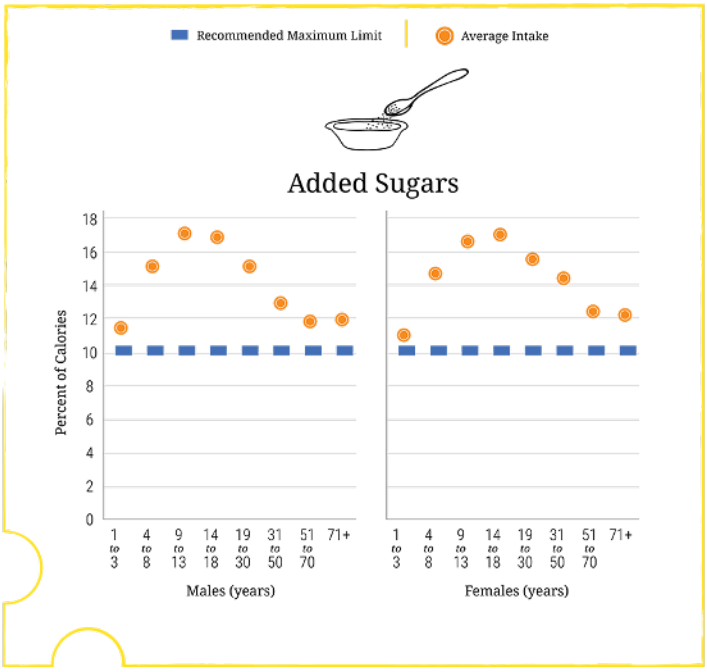


Figure 6.7.4: Average intakes of a*dded sugars as a percent of calories per day by age-sex group, in comparison to the Dietary Guidelines' maximum limit of less than 10 percent of calories.* "Added sugar intake graphics" from Dietary Guidelines for Americans, in the public domain

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.

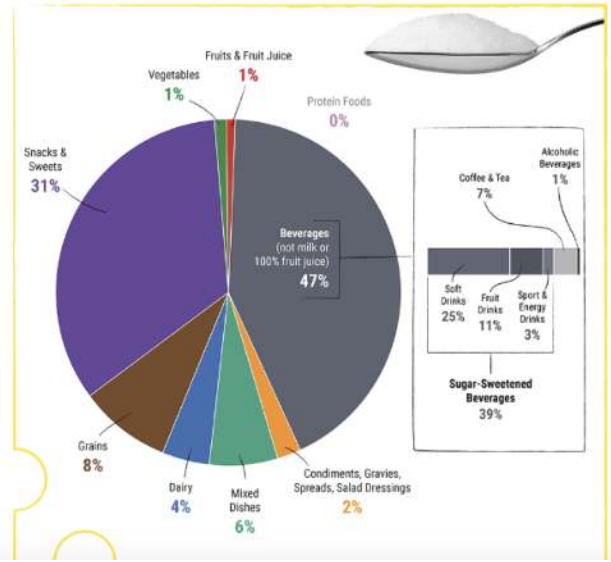


Figure 6.7.5: Food category sources of added sugars in the U.S. population ages 2 years and older. "Added sugar intake graphics" from Dietary Guidelines for Americans, in the public domain

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.

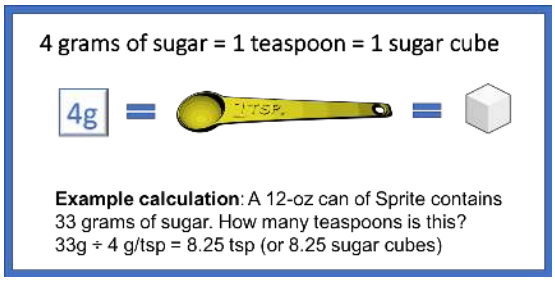


Figure 6.7.6: One teaspoon is equal to 4g of sugar or a sugar cube. "Sugar conversion" by Alice Callahan is licensed under CC BY-NC-SA 4.0, "Sugar cube" by jhnri4 and "measuring spoon" by mazeo, both in the Public Domain

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 6.7.7: Forty six sugar cubes stacked next to a big gulp to illustrate the 46 teaspoons of sugar that the soda contains. "Big Gulp with sugar cubes" by Tamberly Powell is licensed under CC BY-NC-SA 4.0

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.

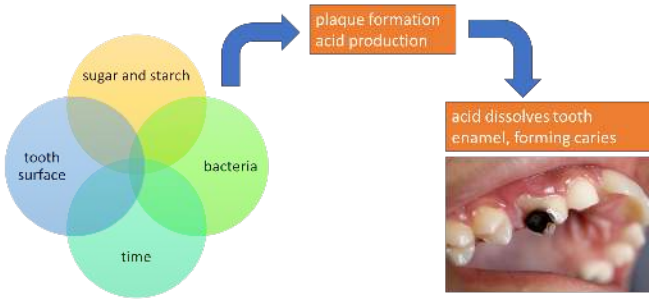


Figure 6.7.8: Dental caries are formed because of a combination of factors: the presence of oral bacteria; a supply of sugar and/or starch for them to eat; tooth surface where they can form colonies, or plaque; and time. "Dental caries" by Alice Callahan is licensed under CC BY-NC-SA 4.0, "cavity" by Suyash.dwivedi is licensed under CC BY-SA 4.0

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."*



Video 6.7.1: "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 6.7.9: Plain yogurt with Nutrition Facts and ingredient list. "Yogurt and label images" by Tamberly Powell is licensed under CC BY-NC-SA 4.0

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 6.7.10: Strawberry yogurt with Nutrition Facts and ingredient list. “Yogurt and label images” by Tamberly Powell is licensed under CC BY-NC-SA 4.0

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 6.7.11: Siggi's plain yogurt and Nutrition Facts. "Yogurt and label images" by Tamberly Powell is licensed under CC BY-NC-SA 4.0

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 6.7.12: Siggi's strawberry yogurt and Nutrition Facts. "Yogurt and label images" by Tamberly Powell is licensed under CC BY-NC-SA 4.0

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.

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6.8: 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 6.8.1: Examples of products containing high-intensity sweeteners: diet soda, sugar-free chocolate, and bulk containers of Splenda and stevia extract. "Diet Hansen's can" by 7 Bits of Truth is licensed under CC BY 2.0; "Sugar-free chocolate" by m01229 is licensed under CC BY 2.0; "Sweeteners" by sriram bala is licensed under CC BY-NC 2.0

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 6.8.1: Sugar substitutes approved by the FDA for use in the United States with their brand names and sweetness relative to sucrose.[3] "Sugar substitutes" by Alice Callahan is licensed under CC BY-NC-SA 4.0

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.

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?



Figure 6.8.2: 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. “Saccharin notice” by Linda Bartlett, National Cancer Institute is in the Public Domain

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 6.8.3: A box of SweetLeaf sweetener, marketed as "Natural Stevia Sweetener." "Stevia" by Mike Mozart is licensed under CC BY 2.0

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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6.9: Research Highlight - Glycemic Index

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 various types of carbohydrates, and the digestion of those carbohydrates. As you read, carbohydrates can all ultimately converted into glucose, but the rate at which that happens and the glucose appears in your bloodstream is different for each food. In the following publication, the authors discuss the development of a glycemic index database to be used with food frequency questionnaires. 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

Neuhouser, M. L., Tinker, L. F., Thomson, C., Caan, B., Horn, L. V., Snetselaar, L., Parker, L. M., Patterson, R. E., Robinson-O'Brien, R., Beresford, S. A., & Shikany, J. M. (2006). Development of a glycemic index database for food frequency questionnaires used in epidemiologic studies. *The Journal of nutrition*, *136*(6), 1604–1609. DOI: https://doi.org/10.1093/jn/136.6.1604

Further evaluation

To evaluate this publication further, it might help to know a little more about the glycemic index.

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1.

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CHAPTER OVERVIEW

7: Lipids

7.1: Introduction to Lipids
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7.3: Lipid Types and Structures
7.4: Fatty Acid Types and Food Sources
7.5: Digestion and Absorption of Lipids
7.6: Lipid Transport, Storage, and Utilization
7.7: Lipid Recommendations and Heart Health
7.8: Research Highlight - Understanding Blood Cholesterol and Heart Disease

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7.1: 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 7.1.1: 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 7.1.1: "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.

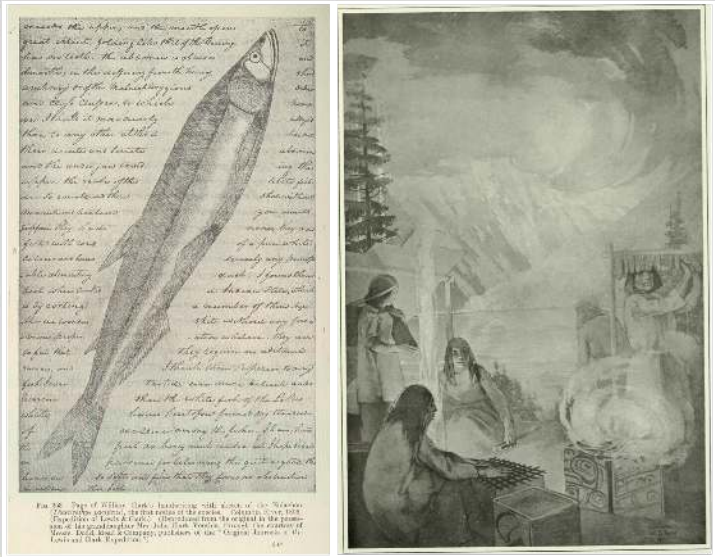


Figure 7.1.3: (left): A page from William Clark's journal of 1805, describing his observations of the euchalon smelt, including its "delicate and luscious" taste. ("Page of William Clark's handwriting with sketch of the Eulachon (Thaleichthys pacificus), the first notice of the species." by David Starr 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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7.2: 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.

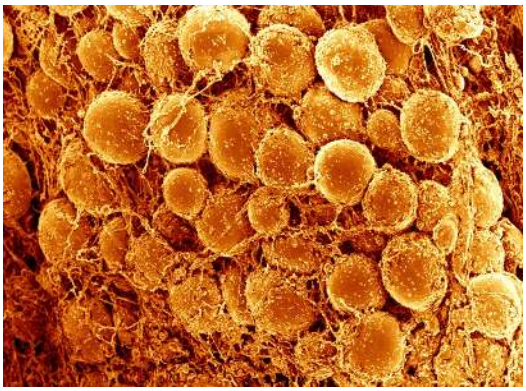


Figure 7.2.1: Scanning electron micrograph of adipose tissue, showing adipocytes. Computer-coloured orange. ("Adipose tissue, close-up showing adipocytes, SEM" by David Gregory & Debbie Marshall is licensed under CC BY 4.0)

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.

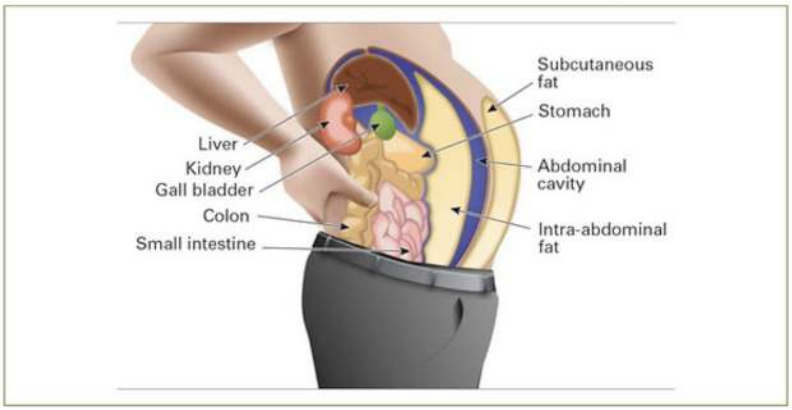


Figure 7.2.2: There are two types of fat stored as adipose tissue: subcutaneous fat and visceral fat. ("Pandemic of Lifestyle Disease" by Sandra Cohen-Rose and Colin Rose is licensed under CC-BY-2.0)

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 The 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 7.2.3: "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, 20116" 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

- University of Hawai'i at Mānoa Food Science and Human Nutrition Program, "The Function of Lipids in the Body," CC BY-NC 4.0

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.
- Obesity Prevention Source. Harvard T.H. Chan School of Public Health. Health Risks: Weight Problems Take a Hefty Toll on Body and Mind. Retrieved from: https://www.hsph.harvard.edu/obesity-prevention-source/obesity-consequences/health-effects/

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7.3: 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.

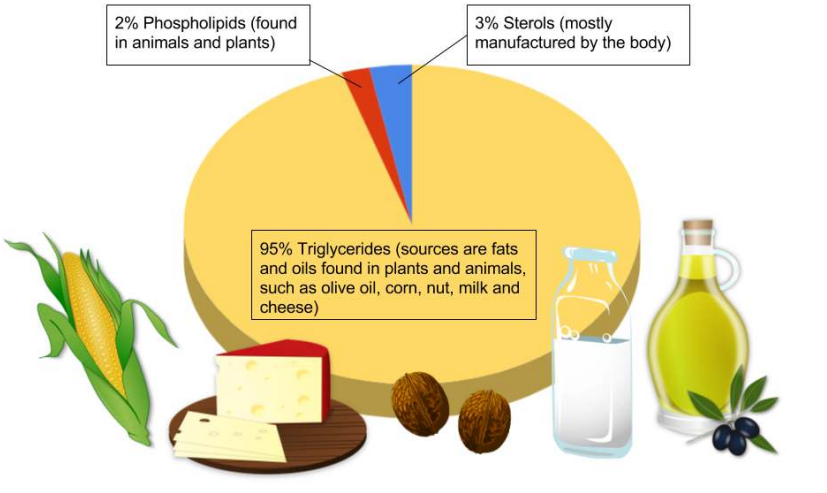


Figure 7.3.1: 95% of fats in the diet are in the form of triglycerides. Sterols (like cholesterol) make up about 3% of dietary fat intake and phospholipids make up roughly 2% of dietary fat intake. "Types of Fat" by Allison Calabrese is licensed under CC BY 4.0

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.

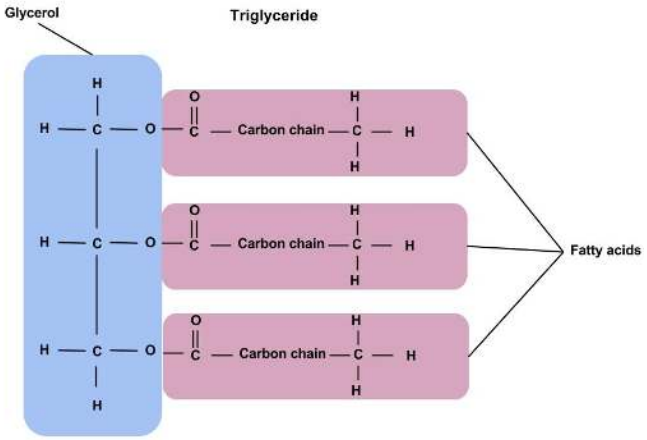


Figure 7.3.2: The chemical structure of a triglyceride, showing the glycerol backbone and three attached fatty acids. “The Structure of a Triglyceride” by Allison Calabrese is licensed under CC BY 4.0

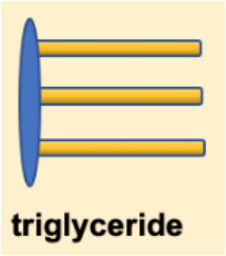


Figure 7.3.3: The structure of a triglyceride is often depicted as a simplified drawing of the glycerol backbone and three fatty acids. “Simple Triglyceride Diagram” by Alice Calahan is licensed under CC BY-SA 4.0

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.

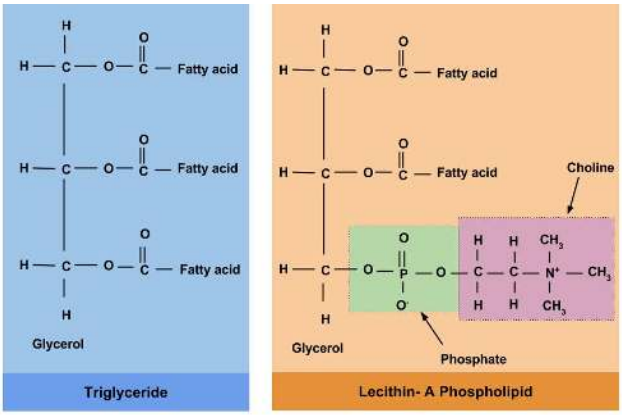


Figure 7.3.4: The structural difference between a triglyceride (on the left) and a phospholipid (on the right) is in the third carbon position, where the phospholipid contains a phosphate group instead of a fatty acid. “The Difference Between Triglycerides and Phospholipids” by Allison Calabrese is licensed under CC BY 4.0

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).

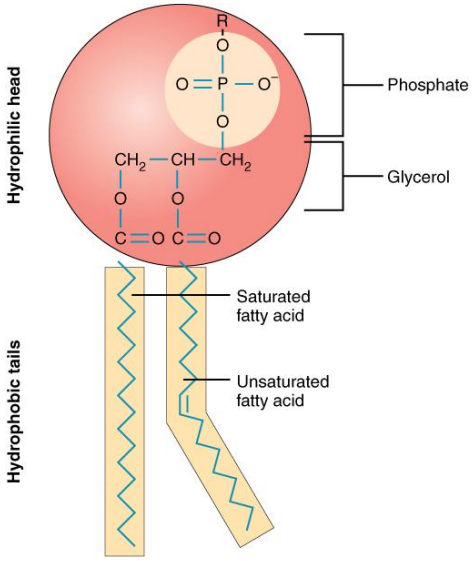


Figure 7.3.5: A phospholipid molecule consists of a polar phosphate "head," which is hydrophilic, and a non-polar lipid "tail," which is hydrophobic. "Phospholipid Structure" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix is licensed under CC BY 4.0

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.

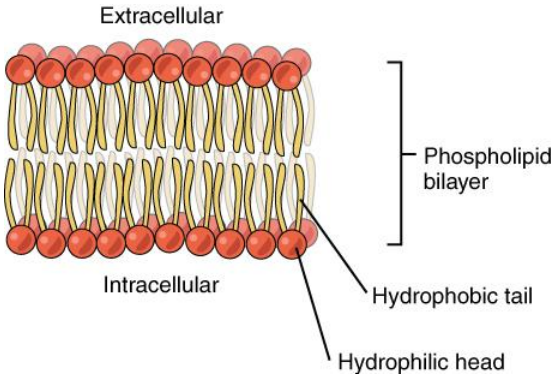


Figure 7.3.6: The phospholipid bilayer consists of two adjacent sheets of phospholipids, arranged tail to tail. The hydrophobic tails associate with one another, forming the interior of the membrane. The polar heads contact the fluid inside and outside of the cell. "Phospolipid Bilayer" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix is licensed under CC BY 4.0

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.



Video 7.3.1: "The Food Lab: Emulsions," by Kenji Lopez Alt, Serious Eats, YouTube (October 22, 2019), 8 minutes. In this episode of the Food Lab video series, Kenji Lopez Alt and Katie Quinn explore what vinaigrettes, mayonnaise, and pasta sauce have in common: emulsification.

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.

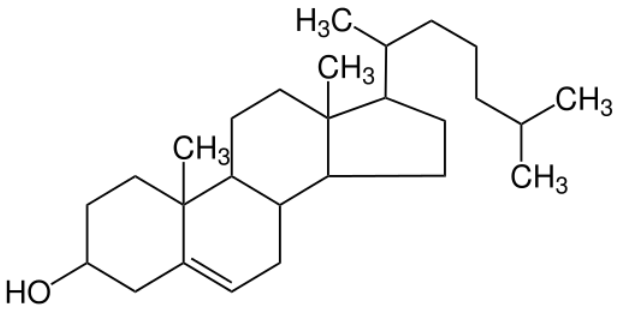


Figure 7.3.7: Cholesterol is made up of multiple carbon rings bonded together. ("Cholesterol Chemical Structure" by Wesalius is in the Public Domain)

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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7.4: 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.

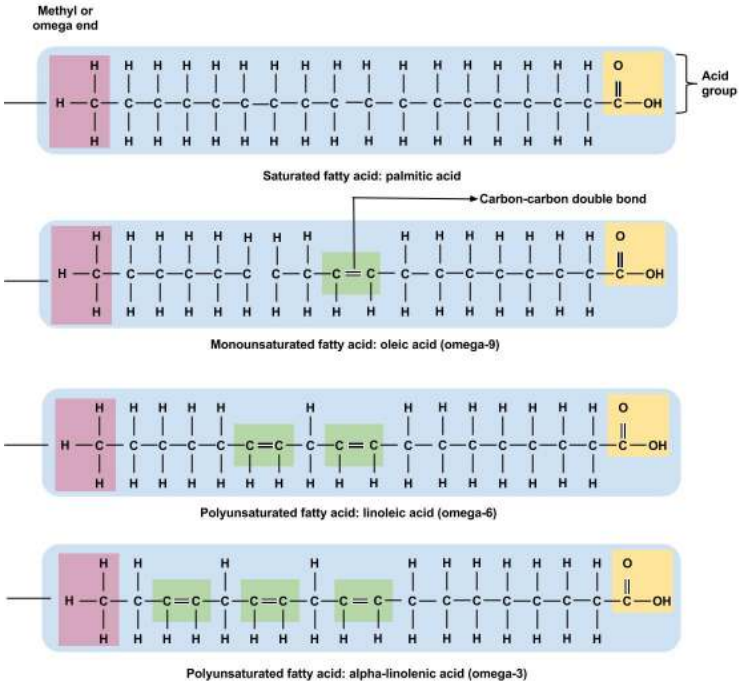


Figure 7.4.1: The structures of a saturated, monounsaturated, and polyunsaturated fat. Note the differences in points of unsaturation (C=C double bonds) on some of the fatty acids. "Structures of a Saturated, Monounsaturated, and Polyunsaturated Fat" by Allison Calabrese is licensed under CC BY 4.0

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. 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.

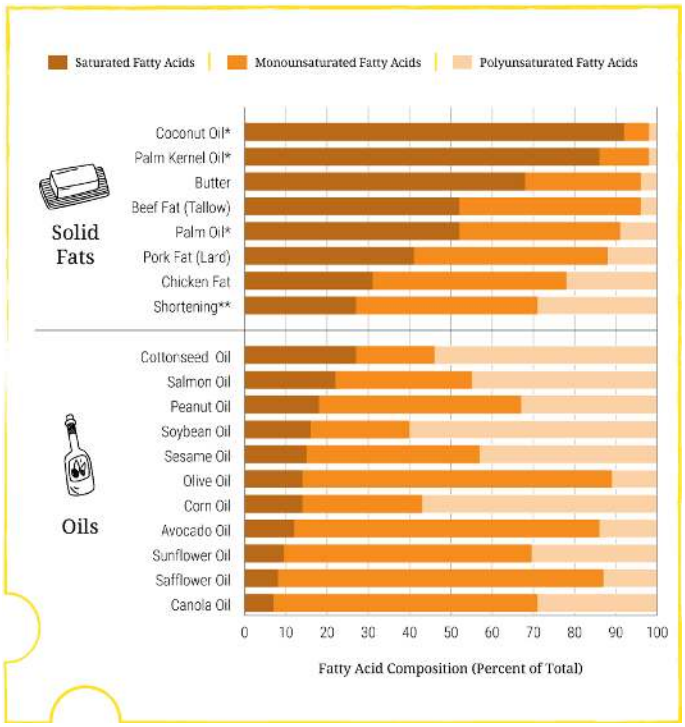


Figure 7.4.2: Dietary fats contain a mixture of saturated, monounsaturated, and polyunsaturated fatty acids. Foods are often categorized by the predominant type of fatty acids they contain, even though foods contain all three types. "Fatty Acid Composition" by Dietary Guidelines for Americans is in the Public Domain

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 sourcesof 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 7.4.3: Examples of foods high in saturated fat, such as meat and dairy products. "Assorted Raw Meats" by Benjamin Ashton is in the Public Domain, CC0; "Butter" by oatsy40 is licensed under CC BY 2.0; "Steak" by Taryn is licensed under CC BY-SA 2.0

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 7.4.4: Examples of foods high in monounsaturated fat, such as olive oil, avocado, nut butters, and seeds. "Clear Glass Cruet Bottle" by Roberta Sorge is in the Public Domain, CC0; "Fruit + Veggie Toast" by ella.o is licensed under CC BY 2.0

Food sources of predominately polyunsaturated fats include plant oils (soybean, corn); fish; flaxseed; and some nuts like walnuts and pecans.



Figure 7.4.5: Examples of foods high in polyunsaturated fats, like fish and nuts. "Raw fish meat on brown chopping board" by Caroline Atwood is in the Public Domain, CC0; "Nuts" by Felix Mittermeier is in the Public Domain, CC0

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.)

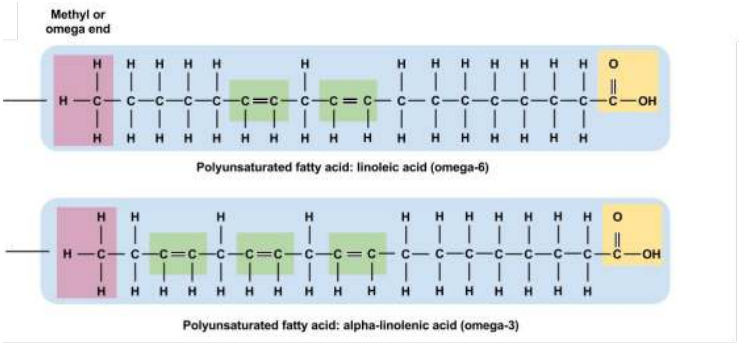
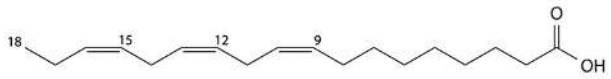
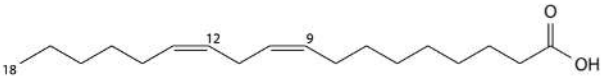


Figure 7.4.6: The position of the first C=C double bond determines whether an unsaturated fatty acid is classified as omega-3 or omega-6. The two essential fatty acids, linoleic acid (an omega-6) and alpha-linolenic acid (an omega-3) are shown here. "Structures of a Saturated, Monounsaturated, and Polyunsaturated Fat" by Allison Calabrese is licensed under CC BY 4.0

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 7.4.7: The chemical structure of the essential fatty acids shown in shorthand, without individual carbon and hydrogen atoms marked. "Alpha-linolenic Acid" is in the Public Domain; "Linoleic Acid" is in the Public Domain

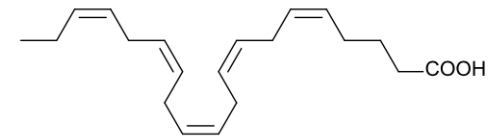
Most Americans easily consume enough linoleic acid and other omega-6 fatty acids, because corn and soybean oil are common ingredients in our food supply. However, sources of ALA and other omega-3 fatty acids are less common in the American diet, and many people could benefit from incorporating more sources 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]

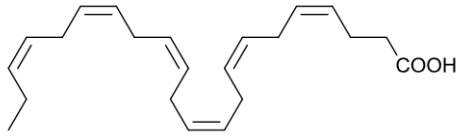
Omega-3 and omega-6 fatty acids are precursors to a large family of important signaling molecules called ***eicosanoids*** (prostaglandins are one type of eicosanoid). Among the many functions of eicosanoids in the body, one of the most important is to regulate inflammation. Without these hormone-like 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.



Eicosapentaenoic acid (EPA)



Docosahexaenoic acid (DHA)

Figure 7.4.8: EPA and DHA are important but non-essential omega-3 fatty acids that can be made in the body from ALA. "Eicosapentaenoic Acid (EPA)" by Minutemen is in the Public Domain; "Docosahexaenoic Acid (DHA)" by Minutemen is in the Public Domain

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 ***trans fatty 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.**

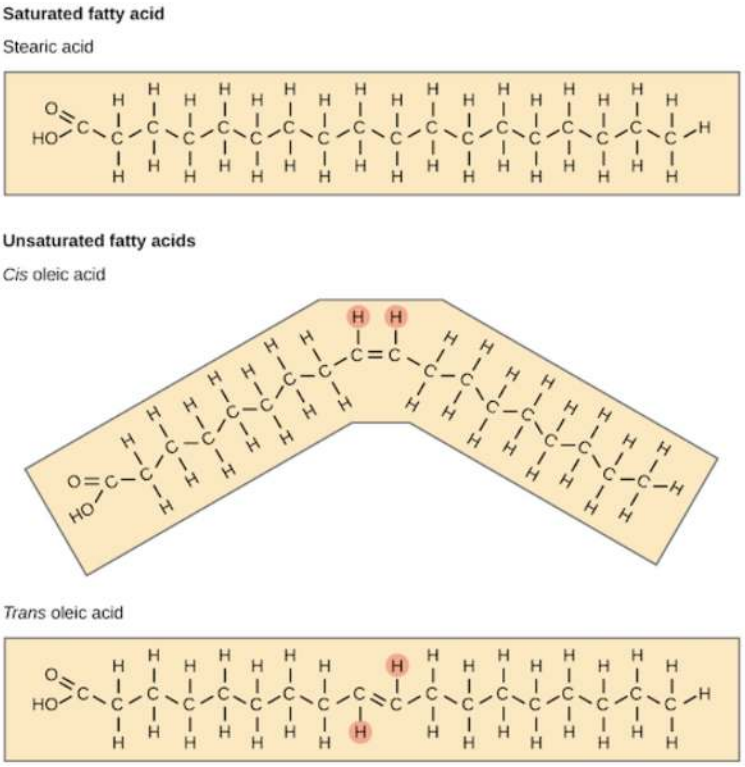


Figure 7.4.9: Comparison of a saturated fatty acid to both the cis and trans forms of an unsaturated fatty acid. "Structures of Saturated, Unsaturated, Cis and Trans fatty Acids" by Allison Calabrese is licensed under CC BY 4.0

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]

Attributions:

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7.5: 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.



Figure 7.5.1: "all eating ice cream" by salem elizabeth is licensed under CC BY 2.0

Let's start at the beginning to learn more about the path of lipids through the digestive tract.

1. 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.

2. 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.

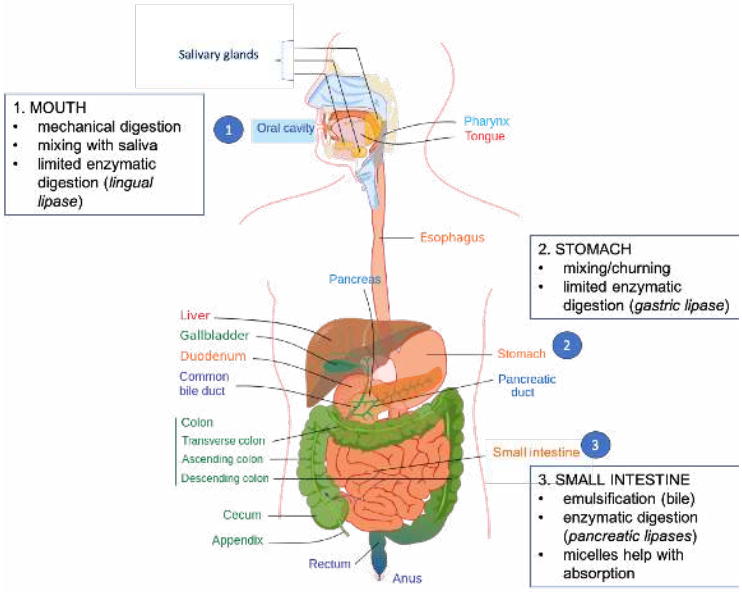


Figure 7.5.2: Overview of lipid digestion in the human gastrointestinal tract. “Overview of lipid digestion” by Alice Callahan is licensed under CC BY 4.0; edited from “Digestive system diagram edit” by Mariana Ruiz, edited by Joaquim Alves Gaspar, Jmarchn is in the Public Domain

3. 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.

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.

4. 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.

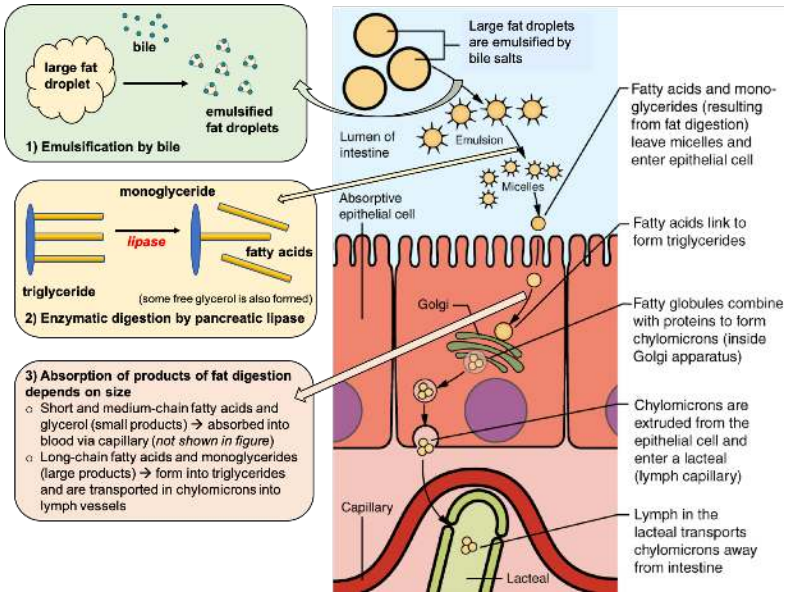


Figure 7.5.3: Lipid digestion and absorption in the small intestine. "Lipid digestion and absorption in the small intestine" by Alice Callahan is licensed under CC BY 4.0; edited from "Lipid Absorption" by OpenStax is licensed under CC BY 4.0

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.

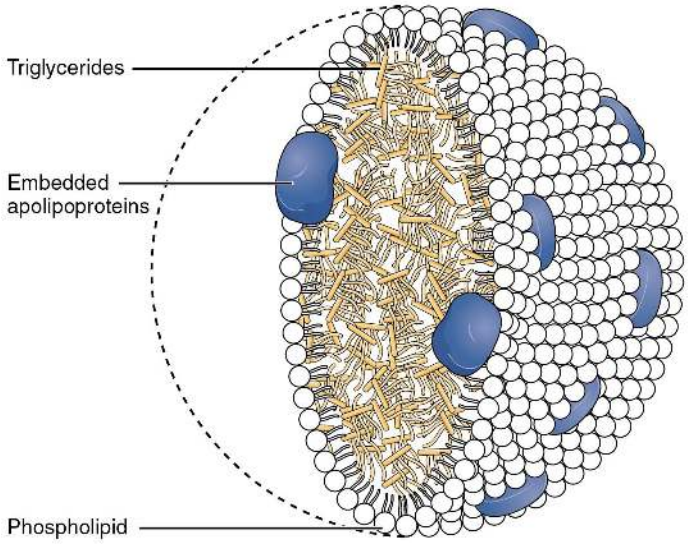


Figure 7.5.1: Structure of a chylomicron. Cholesterol is not shown in this figure, but chylomicrons contain cholesterol in both the lipid core and embedded on the surface of the structure. "Chylomicrons Contain Triglycerides Cholesterol Molecules and Other Lipids" by OpenStax College, Anatomy & Physiology, Connexions Web site is licensed under CC BY 3.0



Video 7.5.1: “Lipids—Digestion and Absorption,” by Alice Callahan, YouTube (November, 17, 2019), 8:49 minutes.

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 7.5.1: “IMGP1686” (breastfeeding baby) by Celeste Burke is licensed under CC BY 2.0

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7.6: 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. Apoliproteins are similarly amphipathic (soluble in both fat and water), a property that makes them useful for aiding in the transport of lipids in the blood.

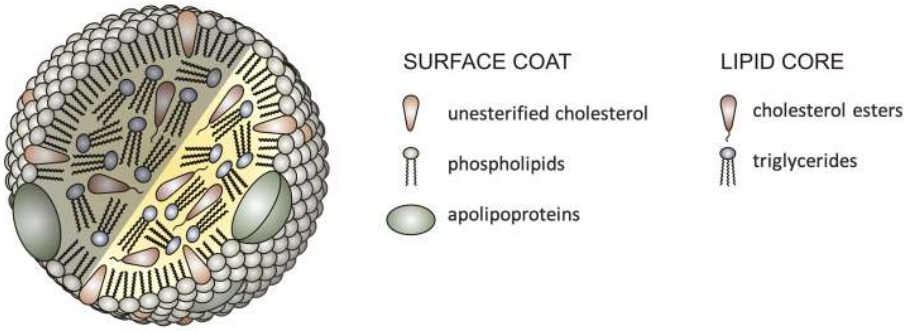


Figure 7.6.1: Basic structure of all lipoproteins. Note the orientation of phospholipids on the surface coat. "Structure of a Lipoprotein" by AntiSense is licensed under CC BY-SA 3.0

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.

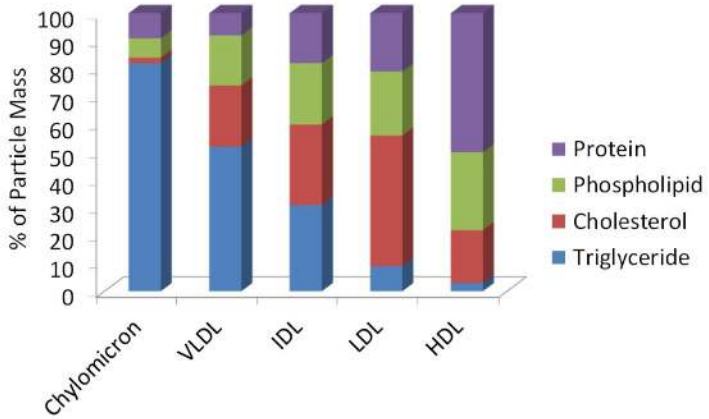


Figure 7.6.1: Comparison of composition of lipoproteins. "Storing and Using Fat" by Allison Calabrese is licensed under CC BY 4.0; with modifications by Alice Callahan.

	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 7.6.1: *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.

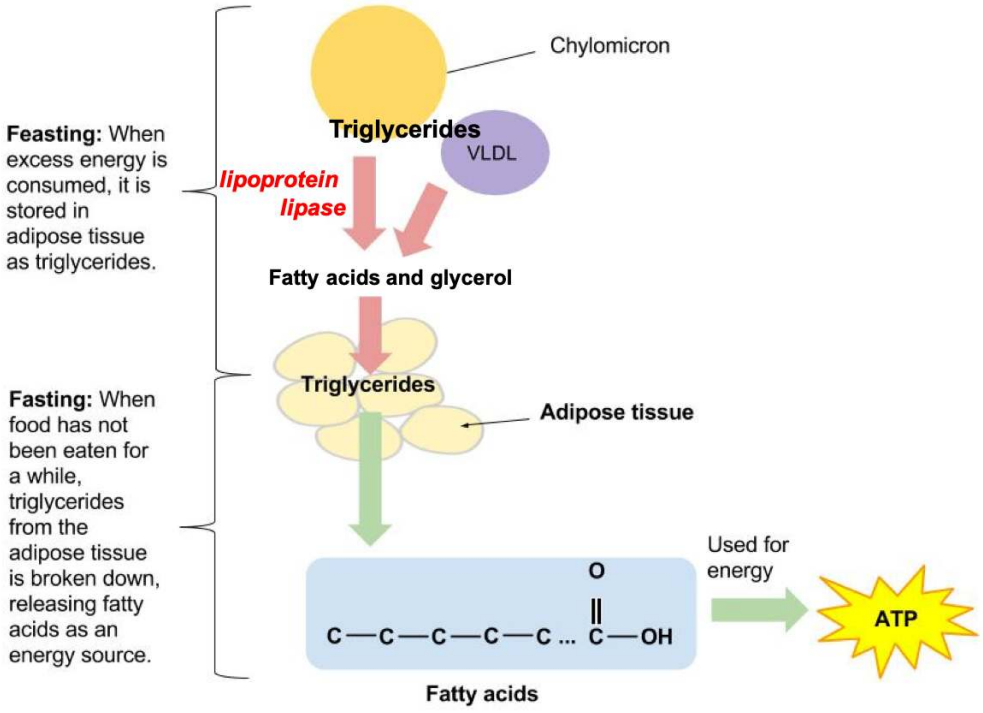


Figure 7.6.2: Triglycerides in chylomicrons and VLDL are broken down by lipoprotein lipase so that fatty acids and glycerol can be used for energ y—or stored for later—in cells. *Comparison of composition, size, density, and function of lipoproteins* by Alice Callahan, CC BY 4.0, including Figure 4.712 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.

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.

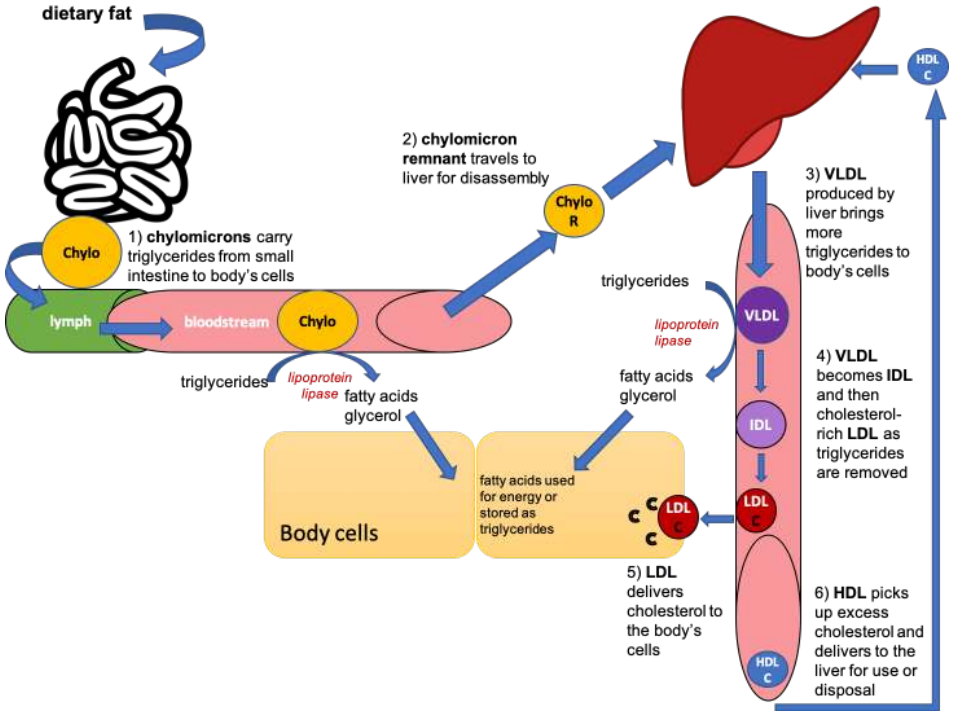


Figure 7.6.3: Overview of lipoprotein functions in the body. Overview of lipoprotein transport and delivery by Alice Callahan is licensed under CC BY 4.0; with liver by maritacovarrubias and small intestine by H Alberto Gongora, both from the Noun Project, CC BY 3.0



Video 7.6.1: "Cholesterol Metabolism, LDL, HDL, and Other Lipoproteins, Animation," by Alila Medical Media, YouTube (May 1, 2018), 3:45 minutes.

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.

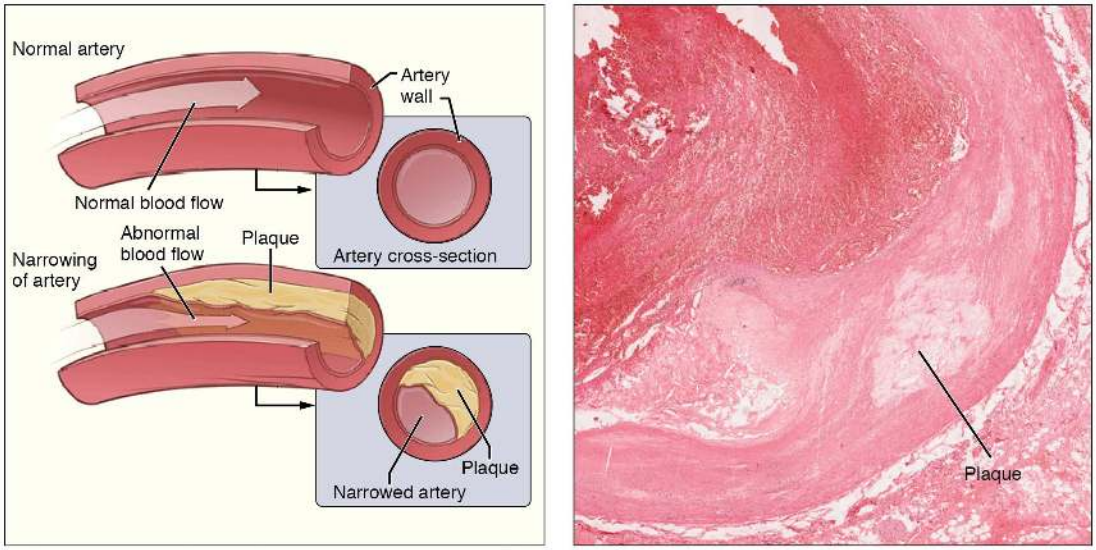


Figure 7.6.1: Atherosclerosis. (a) Atherosclerosis can result from plaques formed by the buildup of fatty, calcified deposits in an artery. (b) Plaques can also take other forms, as shown in this micrograph of a coronary artery that has a buildup of connective tissue within the artery wall. LM × 40. 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]

Attributions

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7.7: 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



Figure 7.7.1: "Traditional stethoscope with a red heart" by Marco Verch is licensed under CC BY 2.0

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.**



Figure 7.7.1: "Pile of Donuts" by Anna Sullivan is in the Public Domain, CC0

According to the 2015 Dietary Guidelines for Americans 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 7.7.1: Examples of heart healthy meals, including fish, nuts, seeds, whole grains, and unsaturated fats. "Healthy Meal" by Louis Hansel is in the Public Domain, CC0; Healthy Brunch Photo by "Healthy Brunch" by Jannis Brandt is in the Public Domain, CC0; "Concept Diet" by Marco Verch is licensed under CC BY 2.0.

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



Figure 7.7.1: "Heart-Shaped Bowl" by Jamie Street is in the Public Domain, CC0

- 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.



Video 7.7.1: "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.

Attributions

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7.8: Research Highlight - Understanding Blood Cholesterol and Heart Disease

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... In the following publication... 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

APA citation

Further evaluation

To evaluate this publication further, it might help to...

Learning Objectives

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

You may have heard of the abbreviations LDL and HDL with respect to heart health. These abbreviations refer to low-density lipoprotein (LDL) and high-density lipoprotein (HDL). Lipoproteins are characterized by size, density, and composition; the various lipoproteins are described in more detail below.

Major Lipoproteins

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

- VLDLs. Very low-density lipoproteins are made in the liver from remnants of chylomicrons and transport triacylglycerols from the liver to various tissues in the body. As the VLDLs travel through the circulatory system, lipoprotein lipase strips the VLDL of triacylglycerols. As triacylglycerol removal persists, the VLDLs become intermediate-density lipoproteins.
- IDLs. Intermediate-density lipoproteins transport a variety of fats and cholesterol in the bloodstream and are a little under half triacylglycerol in composition. While travelling in the bloodstream, cholesterol is gained from other lipoproteins while circulating enzymes strip its phospholipid component. When IDLs return to the liver, they are transformed into low-density lipoprotein.
- LDLs. Low-density lipoproteins are commonly known as “bad cholesterol”. LDLs carry cholesterol and other lipids from the liver to tissue throughout the body. LDLs are comprised of very small amounts of triacylglycerols, and contain over 50% cholesterol and cholesterol esters. As the LDLs deliver cholesterol and other lipids to the cells, each cell’s surface has receptor systems specifically designed to bind with LDLs. Circulating LDLs in the bloodstream bind to these LDL receptors and are

brought into the cell. Once inside the cell, the LDL is taken apart and its cholesterol is released. A deficiency of these LDL receptors will leave a high quantity of cholesterol traveling in the bloodstream, which can lead to heart disease or atherosclerosis. Diets rich in saturated fats limit the number of LDL receptors and thus leave cholesterol in the bloodstream that could be deposited in arteries and block blood flow.

- HDLs. High-density lipoproteins are responsible for carrying cholesterol out of the bloodstream and into the liver, where it is either reused or removed from the body with bile. HDLs have a very large protein composition coupled with low cholesterol content compared to the other lipoproteins. Hence, these high-density lipoproteins are commonly called “good cholesterol.”

Contrasting LDL and HDL

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

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

Blood Cholesterol Recommendations

Desirable blood cholesterol levels for total cholesterol, LDL cholesterol, and HDL cholesterol are included in Table 7.8.1[1]. More specifically, when looking at individual lipid profiles, a low amount of LDL and a high amount of HDL prevents excess buildup of cholesterol in the arteries and wards off potential health hazards. In other words, elevated LDL blood lipid profiles indicate an increased risk of heart attack, while elevated HDL blood lipid profiles indicate a reduced risk.

Table 7.8.1: Blood Cholesterol Classifications

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

Heart Disease

According to the Centers for Disease Control and Prevention (CDC), heart disease is the leading cause of death in the United States[1]. The disease generally starts with atherosclerosis, or a hardening of the arteries. Arteries start to narrow and harden when fats accumulate along their inner walls and form plaques (Figure 7.8.1). A plaque is made of fat, cholesterol, calcium, and other substances found in blood.

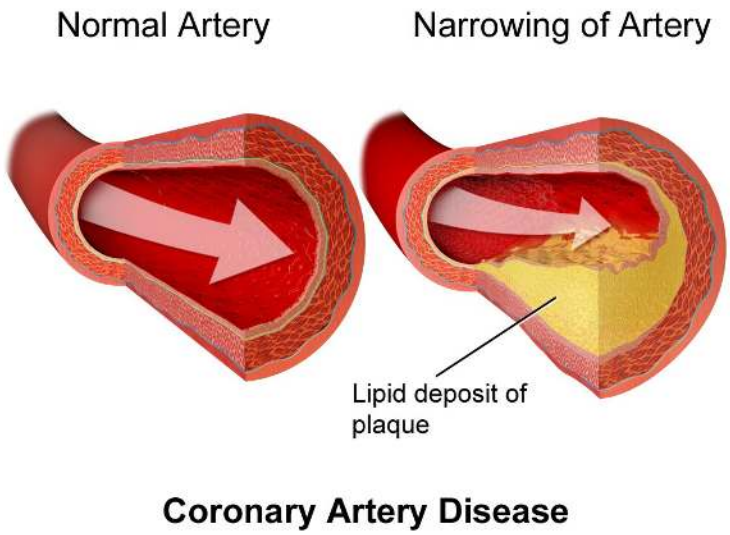


Figure 7.8.1: Illustration comparing a normal blood vessel and partially blocked vessel due to atherosclerotic plaque build-up. Plaque formation along arterial walls impedes blood flow and can create a thrombus, or stationary blood clot.

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

Heart Disease Risk

Risk factors for heart disease include unmodifiable risk factors (that you can't change) and modifiable risk factors that you can change (Table 7.8.2).

Table 7.8.2: Heart Disease Risk Factors

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** Risk increases for men at 45, and for women at 55. • **Gender.** Men have a higher risk than women, though the risk for women rises after menopause. • **Family history.** The more family members who have heart disease, the greater the risk.	• **Cigarette smoking.** Nicotine constricts blood vessels, and carbon monoxide damages their inner lining, which increases the risk of atherosclerosis. • **Obesity.** Excess weight worsens other risk factors. • **Diabetes.** Diabetes is associated with an increased risk of heart disease. • **High blood pressure.** High blood pressure strains the heart. • **Physical inactivity.** Lack of exercise is associated with heart disease. • **Cholesterol levels.** High levels of blood cholesterol can increase the risk. A high level of low-density lipoprotein (LDL), or the "bad" cholesterol, is a common contributing factor. However, a low level of high-density lipoprotein (HDL), or "good" cholesterol, can also promote atherosclerosis.

Steps to Reducing Heart Disease Risk

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

High Blood Pressure

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

High blood pressure is such an important factor in cardiovascular disease, that keeping it within a healthy range is important. Blood pressure is the force of moving blood against arterial walls. Blood pressure readings consist of two numbers and is reported as systolic pressure/diastolic pressure (e.g., 130/90). The top number measures **systolic** pressure (when the heart contracts) and the bottom number measures **diastolic** pressure (when the heart is at rest). The results are recorded in millimeters of mercury (mmHg). The key blood pressure numbers to keep in mind are shown in Figure 7.8.2[5].

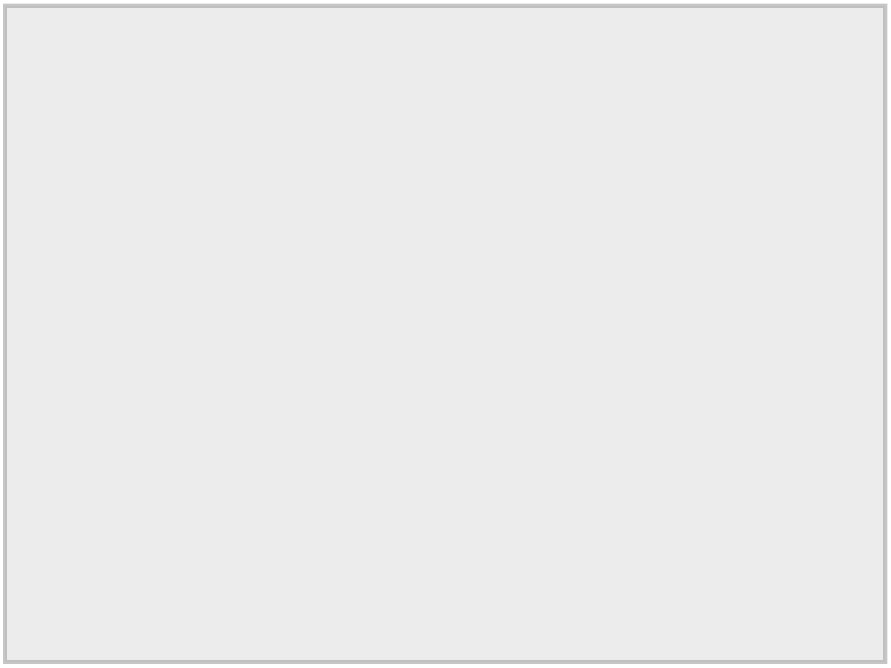


Figure 7.8.2: Blood Pressure Categories

Steps to Reducing the Risk of High Blood Pressure

Techniques to reduce blood pressure include becoming physically active, maintaining a healthy weight, reducing sodium intake, using alcohol moderately, and following the DASH eating plan. The DASH eating plan recommends:

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

Key Takeaways

- Some of the major lipoproteins are VLDL, IDL, LDL, and HDL.

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

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CHAPTER OVERVIEW

8: Protein

8.1: Introduction to Protein
8.2: Protein Structure
8.3: Protein Functions
8.4: Protein in Foods and Dietary Recommendations
8.5: Protein Digestion and Absorption
8.6: Health Consequences of Too Little and Too Much Dietary Protein
8.7: Protein Food Choices and Sustainability

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8.1: 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.



Figure 8.1.1: “Yoga image” by Dave Rosenblum is licensed under CC-BY-2.0.

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8.2: 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.

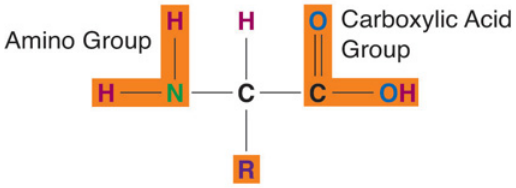


Figure 8.2.1: Amino Acid Structure. “Amino acid structure” from “Defining Protein”, section 6.1 from the book An Introduction to Nutrition (v. 1.0) is licensed under CC BY-NC-SA 3.0

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.

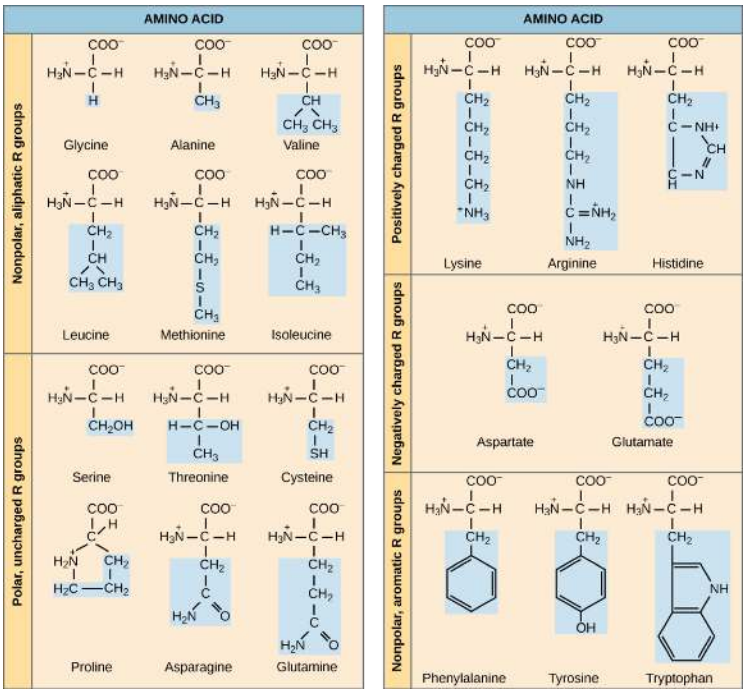


Figure 8.2.2: Amino acids have different structures and chemical properties, determined by their side chains. "Amino acids diagram" from Section 3.4 of Biology by OpenStax is licensed under CC BY 4.0

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 8.2.1: Essential and nonessential amino acids. "Essential and nonessential amino acids" by Tamberly Powell is licensed under CC BY-NC-SA 2.0

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.

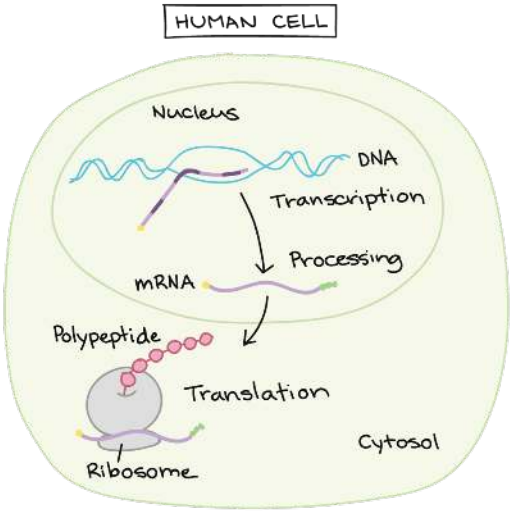


Figure 8.2.3: Overview of protein synthesis. Protein folding happens after translation. "Protein synthesis diagram" from "Intro to gene expression (central dogma)" by Khan Academy is licensed under CC BY-NC-SA 4.0

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).

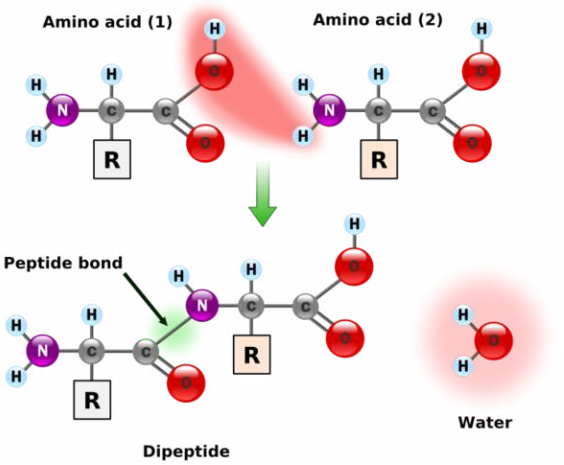


Figure 8.2.4: Peptide bond formation. "Peptide bond formation" by Yassine Mrabet is in the Public Domain

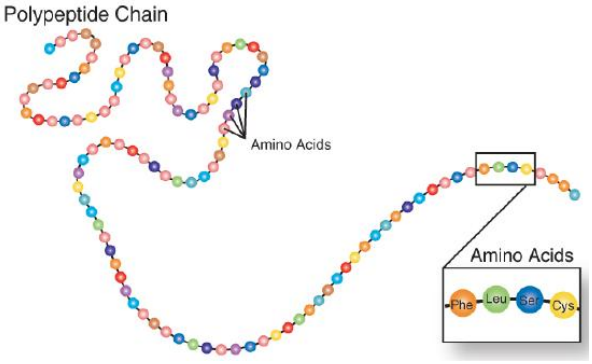
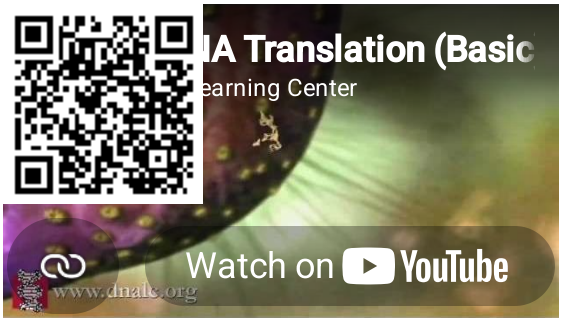


Figure 8.2.5: A polypeptide chain. "Polypeptide chain" by the NIH is in the Public Domain

3. **Protein folding** – The polypeptide chain folds into specific three-dimensional shapes, as described in the next section.



Video 8.2.1: "DNA Transcription," by DNA Learning Center, YouTube (March 22, 2010), 1:52 minutes.



Video 8.2.2: "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 chainof 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.

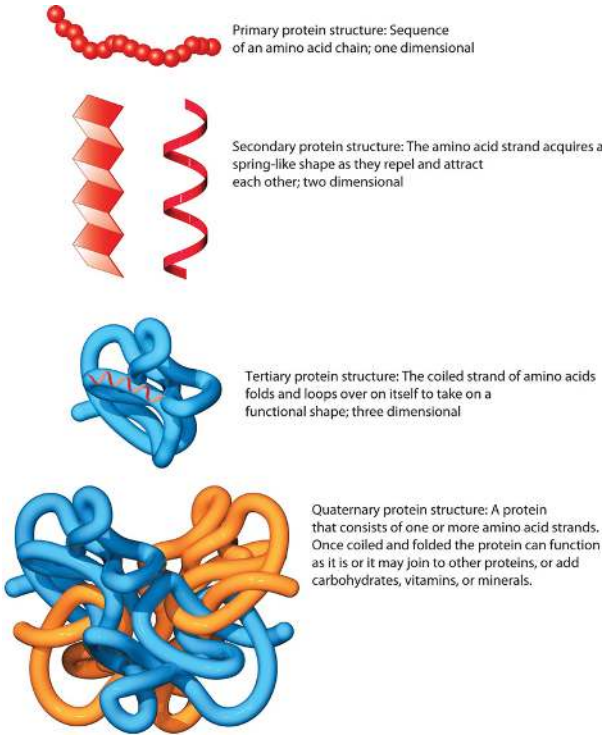
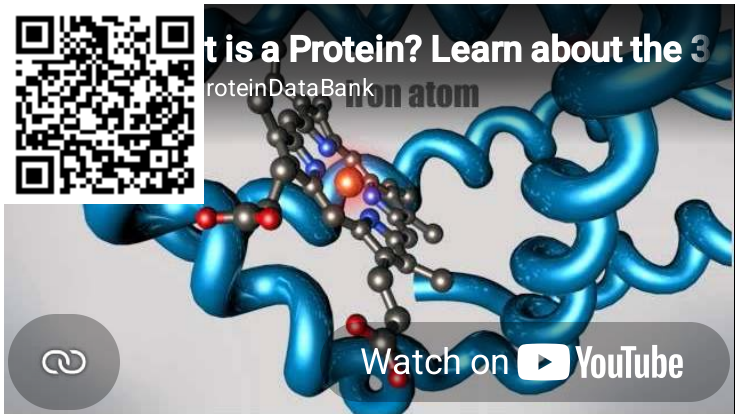


Figure 8.2.6: A protein has four different structural levels. "Structural levels of protein" from "Defining Protein", section 6.1 from the book An Introduction to Nutrition (v. 1.0) is licensed under CC BY-NC-SA 3.0



Video 8.2.3: "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.

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 8.2.7: Structure of hemoglobin. "Hemoglobin" by Richard Wheeler is licensed under CC BY-SA 3.0

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.

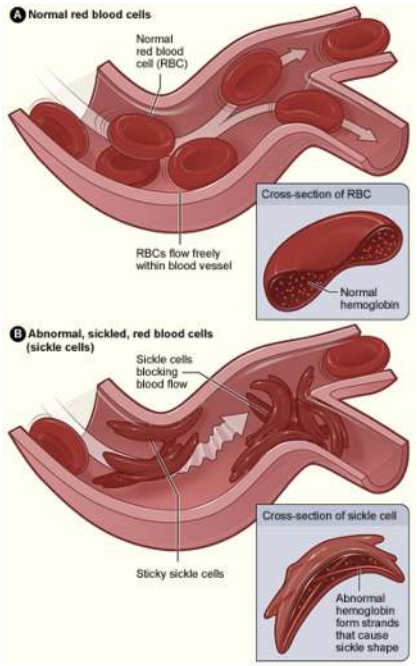


Figure 8.2.8: Difference in blood cells and blood flow between normal red blood cells and sickle shaped blood cells. "Blood flow and red blood cell shape of normal and sickle cell shaped hemoglobin" by The National Heart, Lung, and Blood Institute (NHLBI) is in the Public Domain

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8.3: 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.)

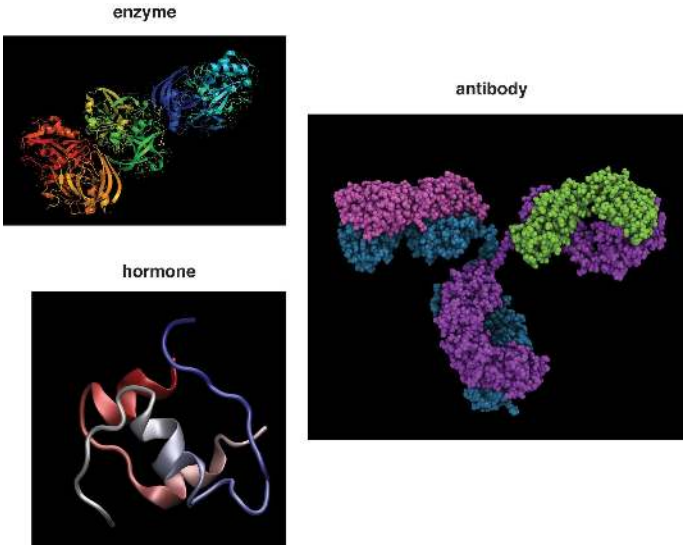


Figure 8.3.1: Examples of proteins with different functions, sizes, and shapes. “Enzyme , antibody, and hormone” from “Protein Functions”, section 6.4 from the book An Introduction to Nutrition (v. 1.0), is licensed under CC BY-NC-SA 3.0

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 8.3.1: Protein types and functions. “Protein types and functions” by Tamberly Powell is licensed under CC BY-NC-SA 2.0

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.

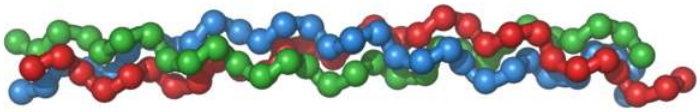


Figure 8.3.2: Triple-helix structure of collagen. "Collagentriplehelix" by JWSchmidt is licensed under CC BY-SA 3.0

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.

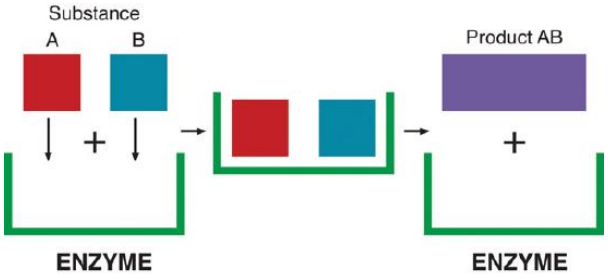


Figure 8.3.3: Enzymes are proteins. An enzyme's job is to provide a site for substances to chemically react and form a product, and decrease the amount of energy and time it takes for this to happen. "Enzyme activity" from "Protein Functions", section 6.4 from the book An Introduction to Nutrition (v. 1.0), is licensed under CC BY-NC-SA 3.0

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 8.3.4: The butterfly-shaped protein, albumin, has many functions in the body including maintaining fluid and acid-base balance and transporting molecules. "Albumin" by Jawahar Swaminathan and MSD staff is in the Public Domain

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.

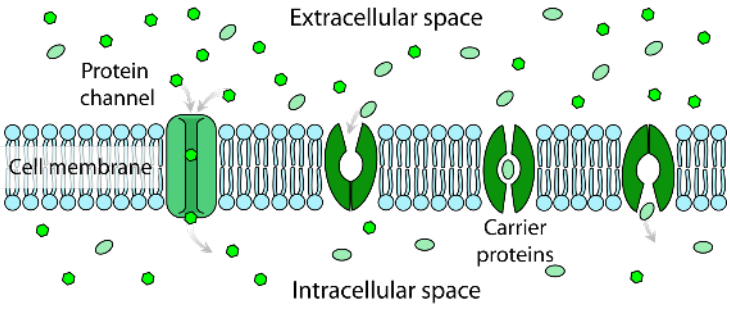


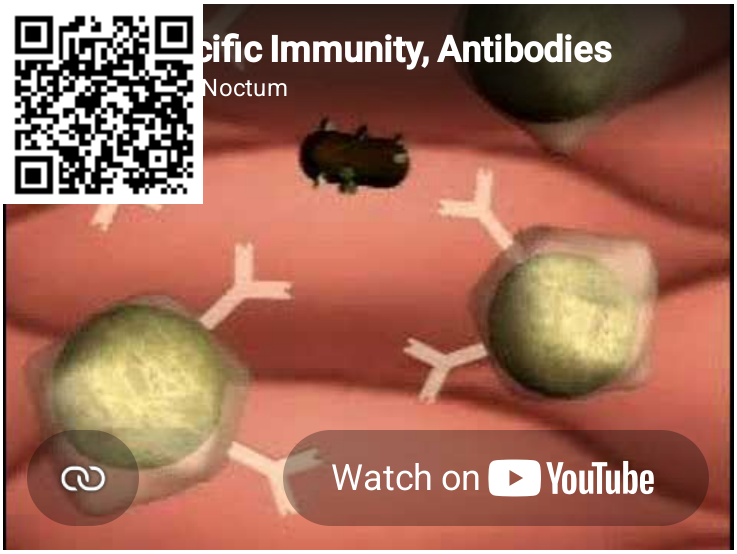
Figure 8.3.5: Molecules move in and out of cells through transport proteins, which are either channels or carriers. "Protein carriers in cell membranes" by LadyofHats, Mariana Ruiz Villarreal is in the Public Domain



Video 8.3.2: "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.



Video 8.3.3: "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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8.4: 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.

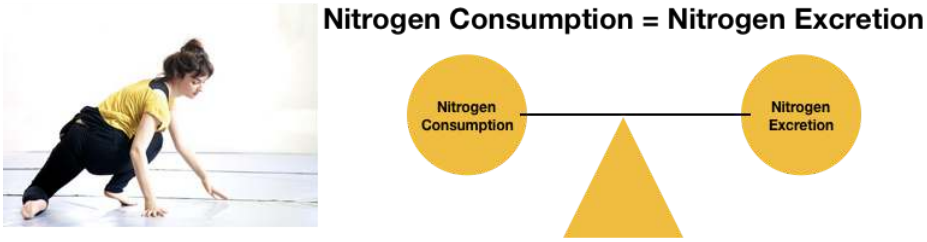


Figure 8.4.1: People are in nitrogen balance when they excrete as much nitrogen as they consume. "Nitrogen balance" by Tamberly Powell is licensed under CC BY-NC-SA 2.0 with "Dancing Exercises" by Forum Danca is licensed under CC BY-NC 2.0

- **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.



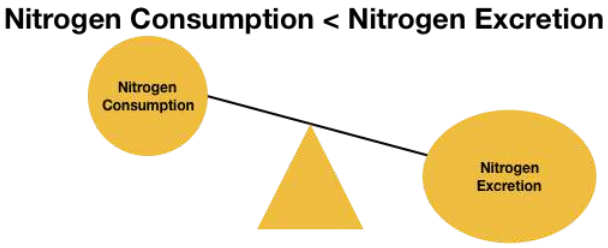


Figure 8.4.2: People are in negative nitrogen balance when they excrete more nitrogen than they consume, usually because they are not eating enough protein to meet their needs. “Negative nitrogen balance” by Tamberly Powell is licensed under CC BY-NC-SA 2.0 with “Indian Prisoners of War” by Chris Turner is licensed under CC BY 2.0

- **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.



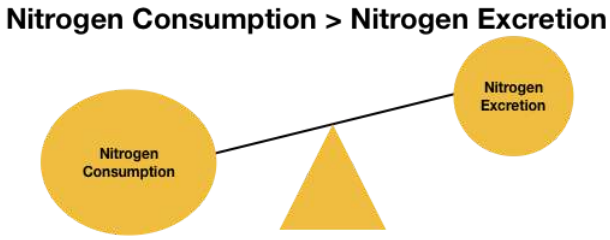


Figure 8.4.3: People are in positive nitrogen balance when they excrete less nitrogen than they consume, because they are using protein to actively build new tissue. “Positive nitrogen balance” by Tamberly Powell is licensed under CC BY-NC-SA 2.0 with “Child at Seoul” by Philippe Teuwen is licensed under CC BY-SA 2.0

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 8.4.1: Protein in common foods[2]. "Protein in common foods" by Tamberly Powell is licensed under CC BY-NC-SA 2.0

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***.



Figure 8.4.4: "Mexican-Rice-and-Beans-2" by Meg H is licensed under CC BY 2.0

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 8.4.2: Complementary protein sources. "Complementary protein sources" by Tamberly Powell is licensed under CC BY-NC-SA 2.0

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]

Attributions:

- "Proteins, Diet, and Personal Choice", section 6.4 from the book An Introduction to Nutrition (v. 1.0), CC BY-NC-SA 3.0

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- [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.
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8.5: 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.

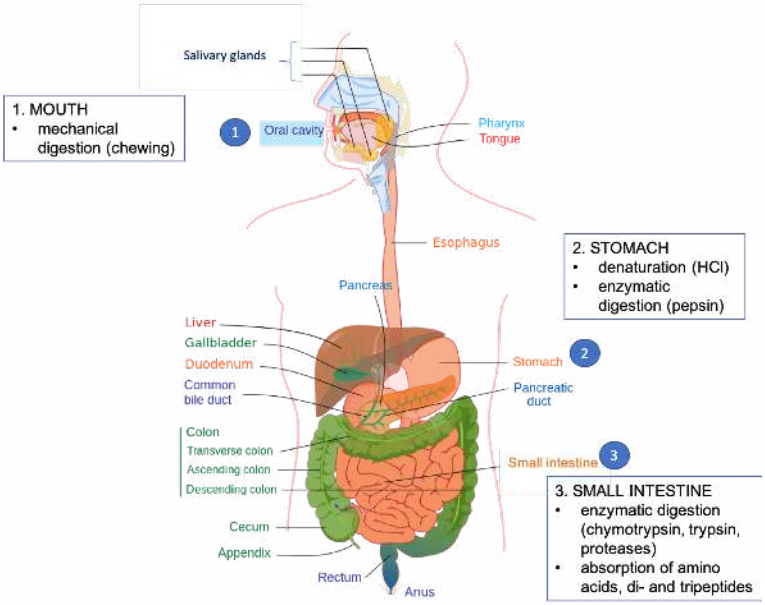


Figure 8.5.1: Protein digestion in the human GI tract. "Protein digestion in the human GI tract" by Alice Callahan is licensed under CC BY 4.0; edited from "Digestive system diagram edit" by Mariana Ruiz, edited by Joaquim Alves Gaspar, Jmarchn is in the Public Domain

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.

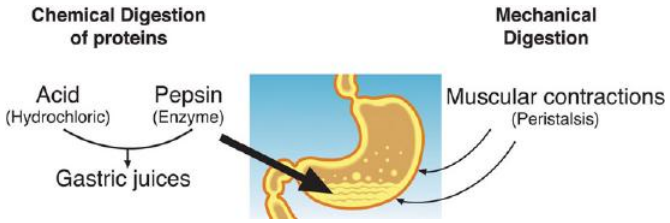


Figure 8.5.2: Protein digestion in the stomach. "Protein digestion in the stomach" from "Protein Digestion and Absorption," section 6.3 from An Introduction to Nutrition (v. 1.0), CC BY-NC-SA 3.0

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.)

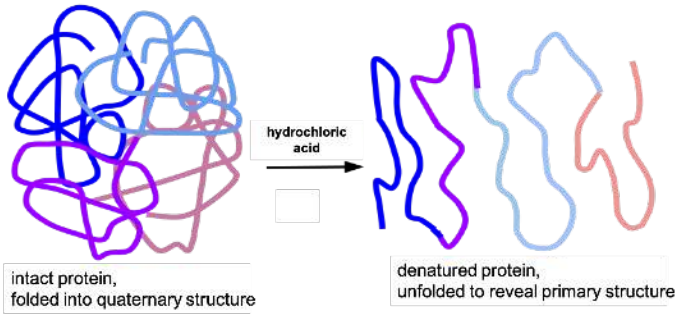


Figure 8.5.3: In the stomach, proteins are denatured because of the acidity of hydrochloric acid. "Denaturation of proteins" by Alice Callahan is licensed under CC BY 4.0; edited from "Process of denaturation" by Scurran is licensed under CC BY-SA 4.0

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.

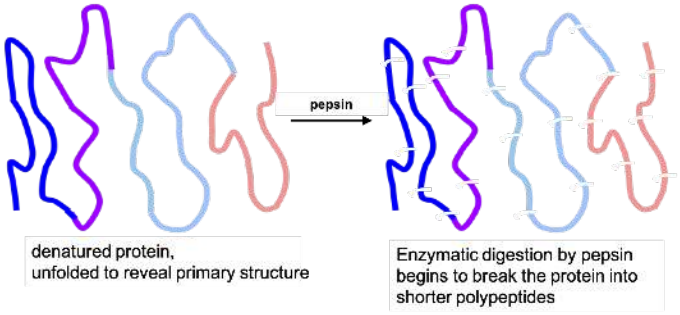


Figure 8.5.4: Enzymatic digestion of proteins begins in the stomach with the action of the enzyme pepsin. "Enzymatic digestion of proteins" by Alice Callahan is licensed under CC BY 4.0; edited from "Process of denaturation" by Scurran is licensed under CC BY-SA 4.0

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.

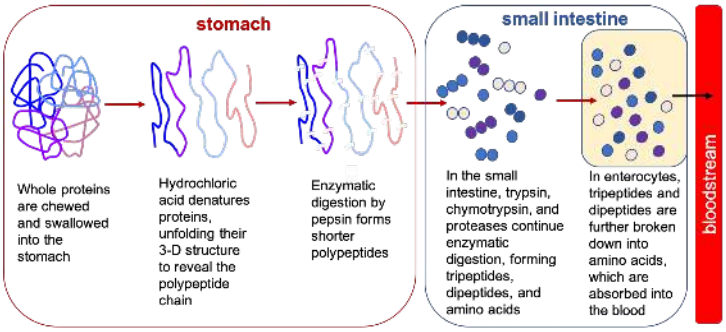


Figure 8.5.5: Summary of protein digestion. Note that the lines representing polypeptide chains in the stomach consist of strings of amino acids connected by peptide bonds, even though the individual amino acids aren't shown in this simplified representation. "Summary of protein digestion" by Alice Callahan is licensed under CC BY 4.0; edited from "Process of denaturation" by Scurran is licensed under CC BY-SA 4.0

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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8.6: 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.



Figure 8.6.1: Diverse human cultures have survived on different levels of dietary protein. The photo on the left shows Inuit families sharing frozen, aged walrus meat. Their traditional diet is very dependent on meat and high in both protein and fat. On the right is a traditional vegetarian meal in India, high in carbohydrates but still providing adequate levels of protein. "Walrus meat" by Ansgar Walk is licensed under CC BY 2.0; "Uttar Pradeshi *thali* (platter)" by GracinhaMarco Abundo is licensed under CC BY 2.0

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

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

Kwashiorkor affects millions of children worldwide. When it was first described in 1935, more than 90 percent of children with Kwashiorkor died. Although the associated mortality is slightly lower now, most children still die after the initiation of treatment.

The name Kwashiorkor comes from a language in Ghana and means, "rejected one." The syndrome was named because it occurs most commonly in children recently weaned from breastfeeding, usually because the mother had a new baby, and the older child is switched to a diet of watery porridge made from low-protein grains. **The child may be consuming enough calories, but not enough protein.**

Kwashiorkor is characterized by swelling (edema) of the feet and abdomen, poor skin health, poor growth, low muscle mass, and liver malfunction. Recall that one of the roles of protein in the body is fluid balance. Diets extremely low in protein do not provide enough amino acids for the synthesis of the protein albumin. One of the functions of albumin is to hold water in the blood vessels, so having lower concentrations of blood albumin results in water moving out of the blood vessels and into tissues, causing swelling. The primary symptoms of Kwashiorkor include not only swelling, but also diarrhea, fatigue, peeling skin, and irritability. Severe protein deficiency in addition to other micronutrient deficiencies, such as folate, iodine, iron, and vitamin C all contribute to the many health manifestations of this syndrome.

Children and adults with ***marasmus*** are protein deficient, but at the same time, they're also not taking in enough calories. Body weights of children with Marasmus may be up to 80 percent less than that of a healthy child of the same age. Marasmus is a Greek word meaning "starvation." The syndrome affects more than fifty million children under age five worldwide. It is characterized by an extreme emaciated appearance, poor skin health, poor growth, and increased risk of infection. The symptoms are acute fatigue, hunger, and diarrhea.



Figure 8.6.2: The photo on the left shows a child suffering from ***kwashiorkor*** *(note the swollen belly) in the late 1960s in a Nigerian relief camp during the Nigerian-Biafran War. The photo on the right shows an Indian child suffering from* ***marasmus.*** "Child with kwashiorkor" by Centers for Disease Control and Prevention is in the Public Domain; "Child with marasmus" by Centers for Disease Control and Prevention is in the Public Domain

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

While severe protein deficiency is rare in the 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.

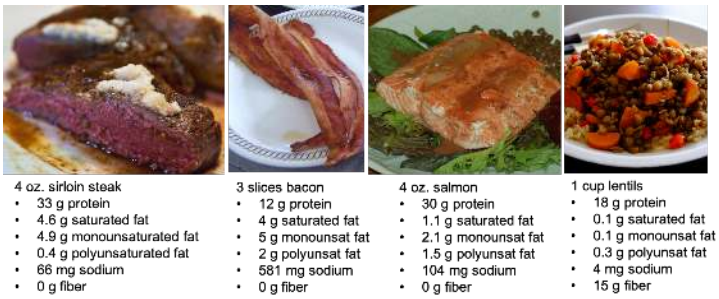


Figure 8.6.3: Compare several different "protein packages." The steak and bacon provide protein but also large amounts of saturated fat and sodium. Salmon provides as much protein as the steak but with less saturated fat and more polyunsaturated fats. Lentils are a good source of protein, are low in fat, and are a great source of fiber. "Sirloin steak" by Steven Depolo is licensed under CC BY 2.0; "bacon" by Bradley Gordon is licensed under CC BY 2.0; "salmon" by Ketzirah Lesser and Art Drau is licensed under CC BY-SA 2.0; "lentils" by Lucas Falcao is licensed under CC BY-NC-ND 2.0

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

- **Osteoporosis** – High protein diets were once thought to increase the risk of osteoporosis, because researchers noticed that urinary calcium excretion increases when people consume high amounts of protein. However, a 2017 systematic review and meta-analysis from the National Osteoporosis Foundation found that this is not a concern, and some studies even show that higher protein intake is associated with greater bone mineral density.[7]
- **Kidney function** – Another concern was that high protein diets would strain the kidneys because of the increased need to filter and excrete nitrogen. A 2018 meta-analysis concluded that this is not a concern. However, people 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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8.7: 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.

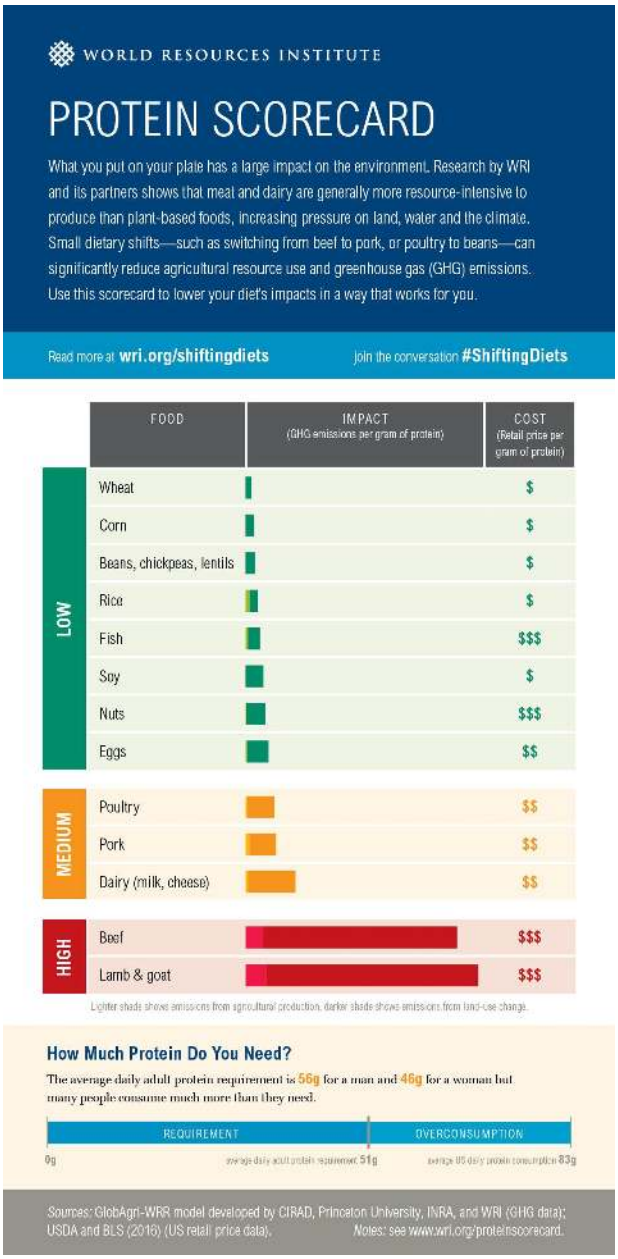


Figure 8.7.1: Protein Scorecard from the World Resources Institute. Source: https://www.wri.org/resources/data-v...tein-scorecard. "Protein Scorecard" from the World Resources Institute is licensed under CC BY-4.0

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

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

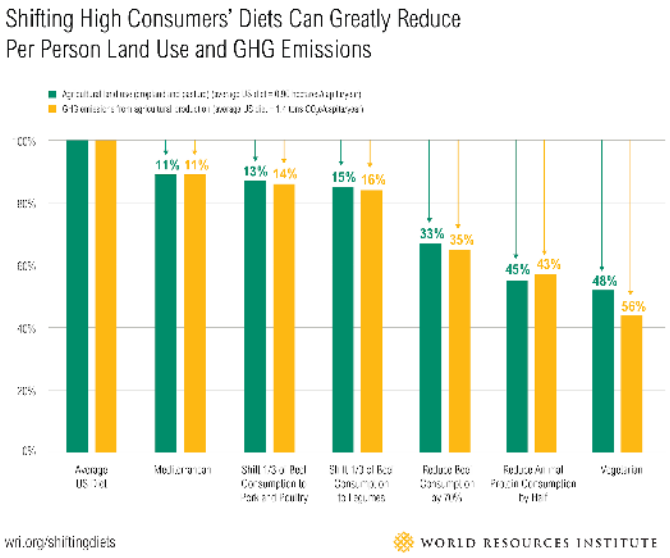


Figure 8.7.2: Shifting High Consumers' Diets Can Greatly Reduce Per Person Land Use and GHG Emissions from the World Resources Institute. Source: https://www.wri.org/resources/charts...nt-based-foods. "Shifting High Consumers' Diets Can Greatly Reduce Per Person Land Use and GHG Emissions" from the World Resources Institute is licensed under CC BY-4.0

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

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

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

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.

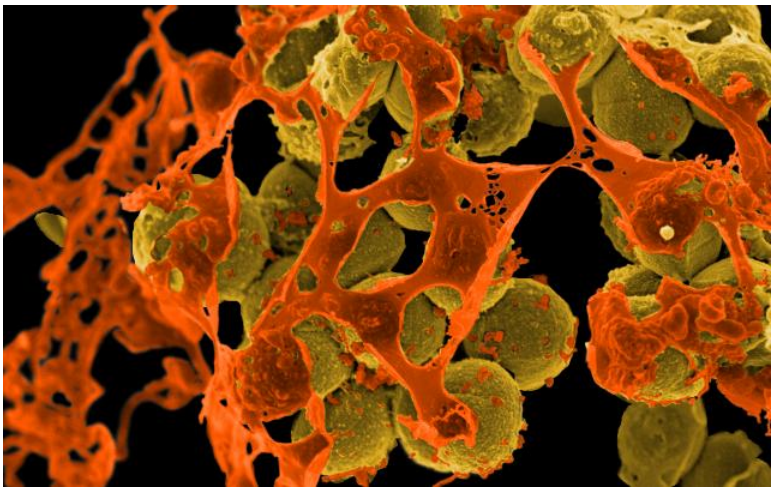


Figure 8.7.3: Scanning electron micrograph of methicillin-resistant Staphylococcus aureus (MRSA, brown) surrounded by cellular debris. MRSA resists treatment with many antibiotics. "Methicillin-Resistant Staphylococcus aureus (MRSA) Bacteria" by NIAID is licensed under CC BY 2.0



Video 8.7.1: "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:

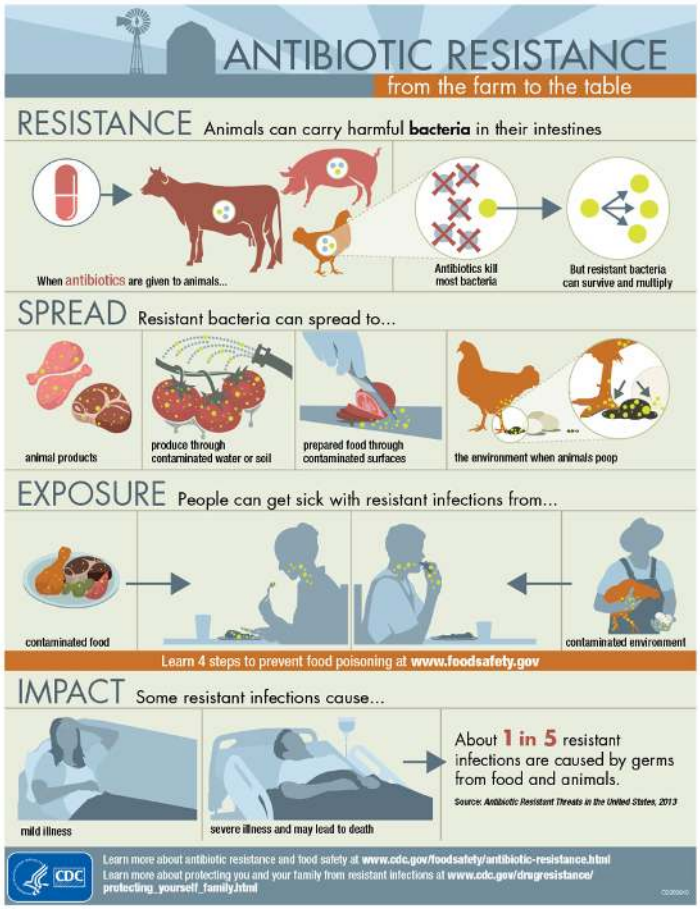


Figure 8.7.4: Antibiotic Resistance from Farm to Table infographic from the CDC. Source: *https://www.cdc.gov/foodsafety/challenges/from-farm-to-table.html*. "Antibiotic Resistance from Farm to Table infographic" from the CDC in in the Public Domain



Video 8.7.2: "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 8.7.5: These eggs are certified organic, so you can be confident that antibiotics weren't used in their production. The sausage is not organic, but it is made from chickens raised without antibiotics, so its production is unlikely to have contributed to the problem of antibiotic resistance. "Egg and sausage labels" by Alice Callahan is licensed under CC BY 4.0

More and more companies are also recognizing how the overuse of antibiotics can contribute to antibiotic resistance, and they're changing their practices. In December 2018, a large consortium of companies and industry groups, including Walmart, McDonald's, and Tyson Foods, committed to a framework for more responsible use of antibiotics.[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 find more information on their website: Monterey Bay Aquarium Seafood Watch.

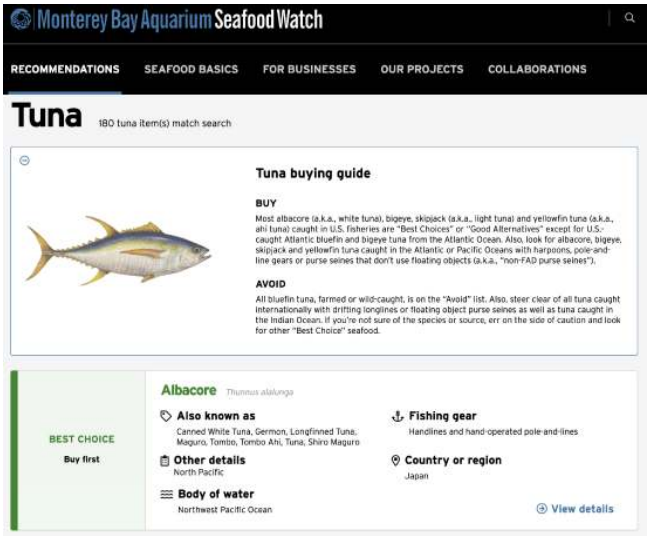


Figure 8.7.6: A screenshot from the Seafood Watch website, showing how it can help you make sense of seafood buying options. "Screenshot from Seafood Watch Website" by Christine Bisson licensed under CC BY 4.0



Video 8.7.3: "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.

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CHAPTER OVERVIEW

9: Energy Balance and Healthy Body Weight

Learning Objectives

After completing this unit, you will be able to:

1. Understand the concepts of energy input and expenditure, energy balance, and how they relate to body weight.
2. Describe the concerns with being underweight and overweight, appreciating that body weight affects a person's physical health but also their mental health and their experience living in a world with unrealistic expectations around body size and shape.
3. Describe the characteristics of a healthy body composition, ways that it can be measured, and limitations to these measurements.
4. Appreciate the global trends in the rising rates of obesity worldwide, and identify possible causes and solutions.
5. Understand the challenge of and best practices for managing body weight in a way conducive to physical and mental health.
6. Acknowledge the importance of a moderate approach when it comes to nutrition and weight management, recognizing all foods can fit into a healthful diet.
7. 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.

9.1: Introduction to Energy Balance
9.2: Energy Balance- Energy In, Energy Out—Yet Not As Simple As It Seems
9.3: Indicators of Health- BMI, Body Composition, and Metabolic Health
9.4: Overweight and Underweight—What are the Risks?
9.5: Obesity Epidemic- Causes and Solutions
9.6: Best Practices For Weight Management

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9.1: Introduction to Energy Balance

On December 26, 2018, 33-year-old Colin O'Brady of Portland, Oregon, became the first person to cross the landmass of Antarctica solo, unassisted, and without any resupply shipments. Others had crossed the continent with the help of a wind sail to propel them over the ice or with resupply drops along the way—both ways of saving precious energy—but O'Brady completed the 926-mile trek only on skis, pulling a sled packed with food, fuel, and supplies the entire way. Speed was important, because he was racing another man, Louis Rudd, a 49-year-old British Army captain. And of course, he didn't want to run out of food hundreds of miles from the finish. Rudd finished the Antarctica crossing just two days after O'Brady.



Figure 9.1. Endurance athlete Colin O'Brady, photographed in March 2016. "Endurance athlete Colin O'Brady in March 2016" by Colin O'Brady is licensed under CC BY-SA 3.0

To prepare for the expedition, O'Brady and his team had to make careful calculations to estimate his nutrient and caloric needs. He'd be skiing all day, 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. " Christopher Michel Antarctica" by Christopher Michel is licensed under CC BY 2.0

But O'Brady also knew that the more food he packed, the heavier his sled would be—ironically making him burn more calories, 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. Still, it's a vitally important concept to understand. We live in a world where food is easily available, and we're constantly bombarded with marketing messages telling us to eat more of it. Not surprisingly, the prevalence of obesity is rising around the globe, and the health effects of carrying too much weight are a concern at both the population and personal levels. On the other hand, being underweight or overly focused on body weight also carry health risks. In this unit, we'll explore these concepts and concerns and seek some answers.

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9.2: 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.

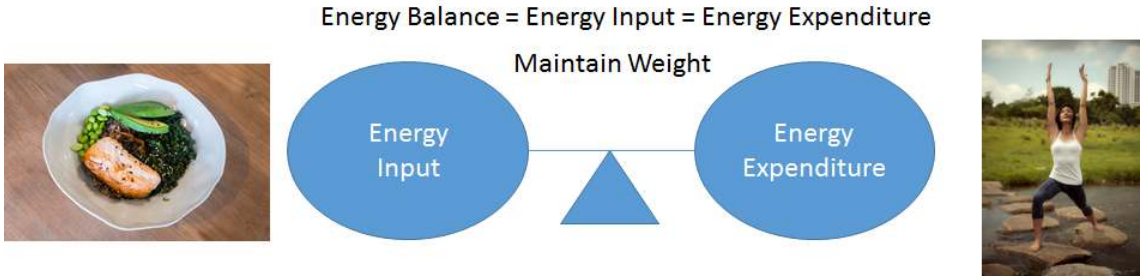


Figure 9.2.1: "Energy balance" by Tamberly Powell is licensed under CC BY-NC-SA 2.0, "Yoga" by Matt Mad is licensed under CC BY-NC-ND 2.0, and "Salmon (sustainable fishing), whole grain wild rice, sesame-spinach, avocado, edamame, home-made teriyaki sauce" by Marco Verch is licensed under CC BY 2.0

Positive energy balance occurs when energy intake is greater than energy expenditure, usually resulting in weight gain.

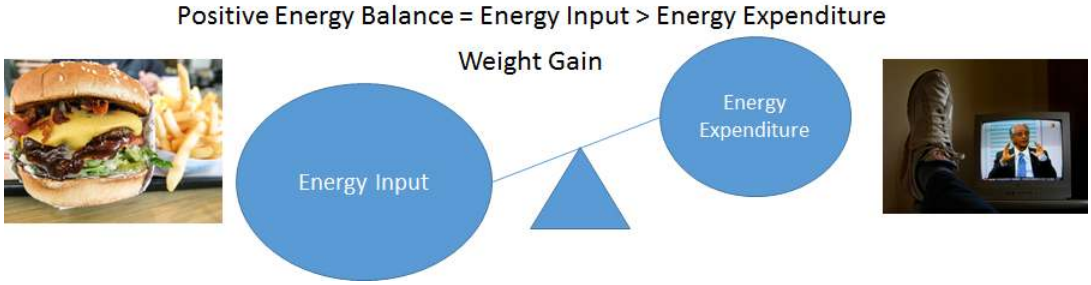


Figure 9.2.2: "Positive energy balance" by Tamberly Powell is licensed under CC BY-NC-SA 2.0, "The Habit: Bacon Cheeseburger" by Person-with-No Name is licensed under CC BY 2.0, and "Watching Gabiera" by Carlos Ebert is licensed under CC BY 2.0

Negative energy balance is when energy intake is less than energy expenditure, usually resulting in weight loss.

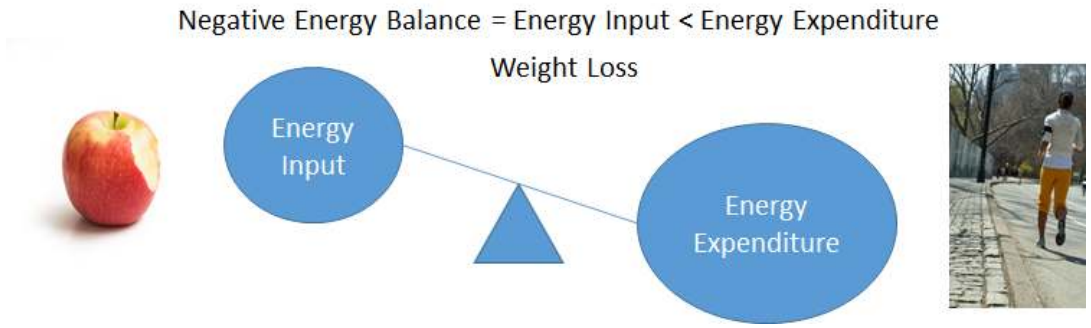


Figure 9.2.3: "Negative energy balance" by Tamberly Powell is licensed under CC BY-NC-SA 2.0, "Bitten Apple" by DLG Images is licensed under CC BY 2.0, and "Exercise" by Andy Cross is licensed under CC BY-NC 2.0

Energy intake 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. In theory, if you consume 3,500 more calories than your body needs, you could potentially gain about one pound, because a pound of fat is equal to about 3,500 calories. If you expend 3,500 more calories than you take in, you could potentially lose about a pound, as your body turns to this stored energy to compensate for the energy deficit. However, in practice, how individuals respond to an excess or deficit of 3500 calories can be quite variable, and over time, the body adapts to these conditions and resists changes in body weight.

Energy balance is complex, dynamic, and variable between individuals—something we'll explore 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

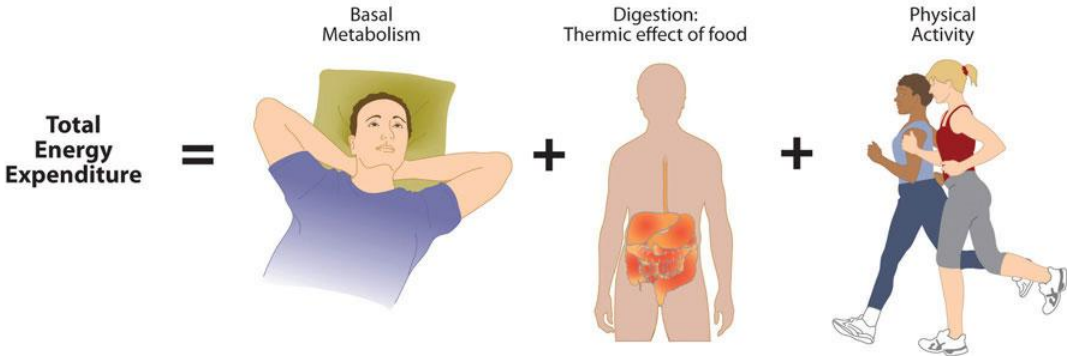


Figure 9.2.4: Components of total energy expenditure include basal metabolism, the thermic effect of food, and physical activity. "Components of total energy expenditure" from "Balancing Energy Input with Energy Output", section 11.2 from the book An Introduction to Nutrition (v. 1.0), CC BY-NC-SA 3.0

1. Basal Metabolic Rate (BMR)

BMR is the energy expended by the body when at rest. These are the behind-the-scenes activities that are required to sustain life. Examples include:

- respiration
- circulation
- nervous system activity
- protein synthesis
- temperature regulation

Basal metabolic rate does not include the energy required for digestion or physical activity.

If a person is sedentary or moderately active, BMR is the largest component of energy expenditure, making up about 60 to 75 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.

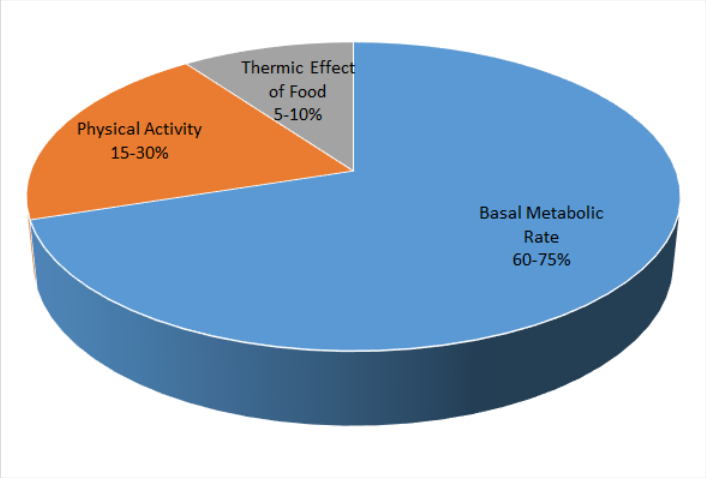


Figure 9.2.5: Components of energy expenditure and their percent contribution to the total in sedentary to moderately active people. "Components of energy expenditure and the percentage they contribute" by Tamberly Powell is licensed under CC BY-NC-SA 2.0

BMR can vary widely among individuals. An individual's lean body mass—made up of organs, bone, and muscle—is the biggest determinant of BMR, because lean body tissue is more metabolically active than fat tissue. This means that a muscular person expends more energy than a person of similar weight with more 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.

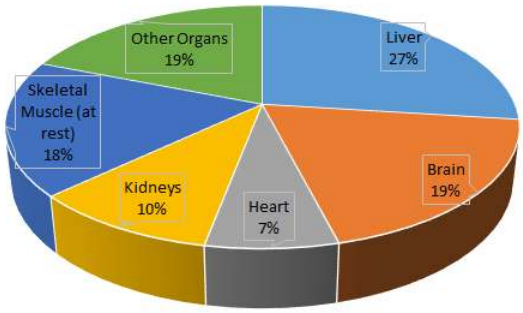


Figure 9.2.6: Energy expenditure of organs. "Energy Expenditure of Organs" by Tamberly Powell is licensed under CC BY-NC-SA 2.0

BMR depends not only on body composition but also on body size, sex, age, nutritional status, genetics, body temperature, and hormones. 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.

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
Pregnancy or lactation	
Stimulants such as caffeine and tobacco	

Table 9.2.1: Factors that Impact BMR. Factors that Impact BMR by Tamberly Powell is licensed under CC BY-NC-SA 2.0

2. Thermic Effect of Food (TEF)

This is the energy needed to digest, absorb, and store the nutrients in foods. It accounts for 5 to 10 percent of total energy expenditure and does not vary greatly amongst individuals.



Figure 9.2.7: "Raking Alternative" by Jack Zalium is licensed under CC BY-ND 2.0

3. Physical activity

Physical activity is another important way the body expends energy. Physical activity usually contributes anywhere from 15 to 30 percent of energy expenditure and can be further divided into two parts:

- exercise-related activity thermogenesis (EAT)
- non-exercise activity thermogenesis (NEAT)

EAT is planned, structured, and repetitive physical activity with the objective of improving health (participating in a sport like soccer or strength training at the gym, for example).

NEAT is the energy expenditure for unstructured and unplanned activities. This includes daily-living activities 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.[1]

NEAT can vary by up to 2,000 calories a day for two people of similar size, according to Dr. James Levine, the Mayo Clinic researcher who first coined the term. NEAT may be an important component of obesity, and is currently an area of research.

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.

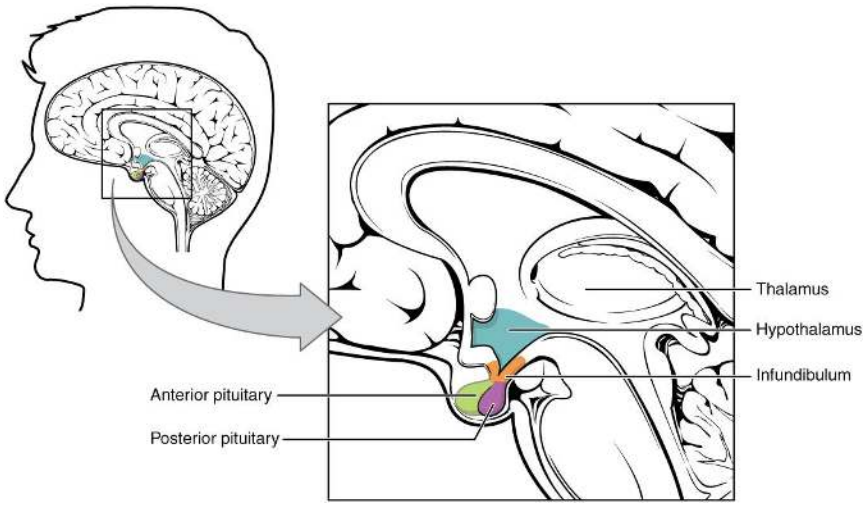


Figure 9.2.8: The hypothalamus, shown in blue, is about the size of an almond and serves as the hunger center of the brain, receiving signals from the gastrointestinal tract, adipose tissue, and blood and signaling hunger and satiety. "The Hypothalamus-Pituitary Complex" by OpenStax College is licensed under CC BY-SA 3.0

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.[2]

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 aid in the digestion of nutrients.[2]

Fat tissue also plays a role in regulating food intake. Fat tissue is the primary organ that produces the hormone ***leptin***, and as fat stores increase, more leptin is produced. Higher levels of leptin communicate to the satiety center in the hypothalamus that the body is in positive energy balance. Leptin acts on the brain to suppress hunger and increase energy expenditure. The discovery of leptin's functions sparked a craze in the research world and in the diet pill industry, as it was hypothesized that if you give leptin to a person who is overweight, they will decrease their food intake. In several clinical trials, it was found that people who are overweight or obese are actually resistant to the hormone, meaning their brain does not respond as well to it. Therefore, when you administer leptin to an overweight or obese person, there is generally no sustained effect on food intake.[3]

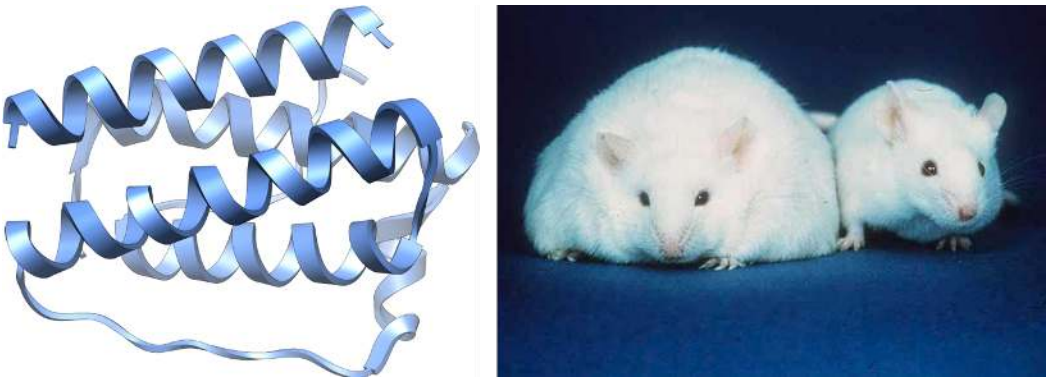


Figure 9.2.9: The structure of the hormone leptin (left), which is primarily produced by adipose tissue. The obese mouse in the photo has a gene mutation that makes it unable to produce leptin, resulting in constant hunger, lethargy, and severe obesity. For comparison, a mouse with normal leptin production 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. "Leptin" by Vossman is licensed under CC BY-SA 3.0; "Fatmouse" by Human Genome wall for SC99 is in the Public Domain

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, including in response to each other.[4,5]

Let's first look at the energy intake side. As we've already discussed, how much food we eat each day is not just a matter of willpower or self-control. It's the result of powerful physiological and psychological forces that tell us if we need to eat, or if we've had enough. Our brains are hard-wired to seek food if we're in negative energy balance, an instinct required for survival. This means that if you start to exercise more—increasing your energy expenditure—you will also feel hungrier, because your body needs more fuel to support the increase in physical activity. If you eat fewer calories, perhaps in an effort to lose weight, your stomach will produce more ghrelin, and your adipose tissue will produce less leptin. These shifting hormone levels work together to increase hunger and make you focus on obtaining more calories. People who try to gain weight run into the opposite problem. Their leptin levels increase, suppressing hunger. It's also uncomfortable to eat beyond satiety, and food doesn't taste as good.

Even measuring how much energy is consumed is not as simple as you might think. We can measure the caloric content of food from a chemical standpoint, but we can only *estimate* how much energy a person will absorb from that food. This will depend on how well the food is digested and how well the macronutrients are absorbed—factors 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 going into negative energy balance cause a drop in BMR to conserve energy. Muscles also become more efficient, requiring less energy to work, and without realizing it, people in negative energy balance often decrease their NEAT activity level. These adaptations help to conserve body weight and make it more difficult to stay in negative energy balance. People may still be able to lose weight despite their bodies working to prevent it, but maintaining a new, lower weight requires constant vigilance, and weight regain is common.

Research has also shown that people respond differently to positive energy balance. When a group of people are overfed, the amount of weight gained 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.[6] People gain and lose weight differently; we don't necessarily follow formulas.

When people say that the answer to the obesity epidemic is to eat less and move more, they're not wrong. But this is also an oversimplified answer, because of all the complexities underlying energy intake and energy expenditure.

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9.3: Indicators of Health- BMI, Body Composition, and Metabolic Health

Determining Your Healthy Size

There are many metrics used to assess body composition (and we'll discuss some of these later), but none give a complete picture of an individual's health. That requires a truly individual assessment, not just of numbers on the scale, but of a person's overall health and well-being in the context of family history and lifestyle.

Here's how the authors of the text, "Sport Nutrition for Health and Performance" describe a healthy body weight:

- *A weight that is appropriate for your age and physical development*
- *A weight you can achieve and sustain without severely curtailing your food intake and constantly dieting*
- *A weight that is compatible with normal blood pressure, lipid levels, and glucose tolerance (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*

Overall, a healthy size should not be dictated by a formula, the latest fad, or societal expectations. People come in all shapes and sizes, and you have to determine what a healthy size is for you. Yet it's also worth understanding some of the measures used to estimate body composition, how they can be linked to health, and their limitations.



Figure 9.3.1: "Walking exercise" by bluesbby is licensed under CC BY 2.0

Body Mass Index

Body Mass Index (BMI) is an inexpensive screening tool used in clinical and research settings to assess body weight relative to height. Because it takes height into account, it is more predictive of how much body fat a person has than weight alone. However, BMI is not a direct measure of body fat, so it shouldn't be used on its own to diagnose obesity or the health of an individual.[1]

BMI calculations and categories

BMI is calculated using the following equations:

$$\text{BMI} = [\text{weight (kg)}/\text{height (m}^2\text{)}]$$

OR

$$\text{BMI} = [\text{weight (lb)}/\text{height (in}^2\text{)}] \times 703$$

The Centers for Disease Control and Prevention has a BMI calculator on its website: https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/english_bmi_calculator/bmi_calculator.html

For adults, BMI ranges are divided into four categories, which are associated with different levels of health risk:

- **Underweight –** BMI < 18.5
- **Normal weight –** BMI from 18.5-24.9
- **Overweight –** BMI from 25-29.9
- **Obese –** BMI from 30 or higher

Obesity is frequently subdivided into categories:

- **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 with age and can be different between boys and girls.)

In general, BMI in the "normal" range is associated with better health compared to both underweight and overweight or obese values, because there are risks of carrying both too little and too much body fat. When researchers have looked at BMI and health in large groups of people, they generally find that the lowest risk of disease and of dying younger is in the range of BMI of 20 to 25. As BMI values increase into the overweight and obese ranges, the risk of developing type 2 diabetes, cardiovascular disease and stroke, and even cancer increase, as well as other complications of obesity, such as osteoarthritis.[2,3,4] Carrying extra weight not only puts a mechanical strain on the body, but it also negatively impacts metabolic health and increases inflammation.[5]

Limitations of BMI

The advantage of BMI is that it's simple and easy to calculate, but it also has several important limitations. Since it's only based on weight and height, it doesn't distinguish between muscle mass and adipose tissue. It's not unusual for muscular athletes to be classified as overweight based on BMI, but this can be misleading, because they may have little to no excess body fat. On the flipside, 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.

All of this means that BMI is not particularly useful for comparing one individual to another individual or even one population to another, because this one number simply doesn't account for all of the underlying diversity in factors like body type, muscle mass, biological sex, and race. And for an individual, one BMI measurement at a single point in time may not be all that meaningful—other measurements and clinical assessments are needed to diagnose obesity and more accurately assess disease risk, as we'll discuss in a moment.

BMI is perhaps most useful for tracking *changes* in body composition over time, whether of a population or an individual. For example, the data on average BMI in the U.S. show a clear increase over the last several decades, and the most likely explanation for that is not that people in the U.S. are all gaining several pounds of muscle each year, but that we're putting on more fat. On the other hand, someone may have a BMI classified as overweight, but if they've been at that BMI their entire adult life and are active and metabolically healthy, that may just be the natural size and shape of their body.

Measuring Body Composition

A person's body mass is made up of water, lean body mass (including organs, bone, and muscle), fat, and other components like minerals. The weight on the scale does not distinguish between these different components, but body composition measurements can.

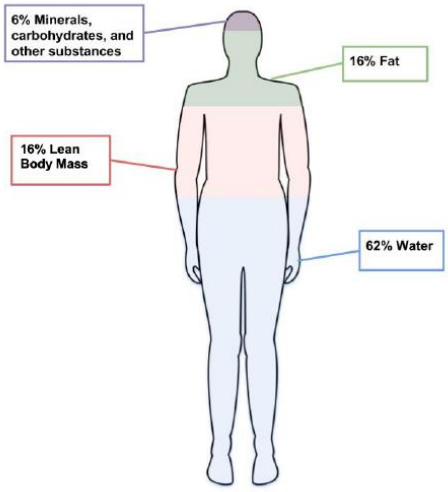


Figure 9.3.2: C*The four main components of body weight are water, fat, lean body mass and other components like minerals.* "Components of weight" by Allison Calabrese is licensed under CC BY 4.0

Body composition measurements are used by individuals and researchers to determine how much of a person's weight is made up of body fat and lean body mass. An individual might use body composition measurements to track their progress in building muscle with a new strength training program. Since increased body fat is often a risk factor for diseases like cardiovascular diseases and diabetes, researchers are often interested in this type of data. There are several different methods used to measure body composition, each with advantages and limitations.[6]

- **Skinfold test**. This is a simple, non-invasive, and low-cost way to assess fat mass. Calipers are used to measure the thickness of skin on three to seven different parts of the body, and these numbers are then entered into a conversion equation. Keep in mind that the accuracy of the skinfold test depends on the skill of the person taking the measurements, the accuracy of the calipers, and the appropriateness of the conversion equations. Best practice is for the same person to take repeated measurements if using them to monitor changes over time. Repeated measurements by different technicians, using different calipers, and different conversion equations will yield very different results.



Figure 9.3.3: 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 9.3.4: BIA hand device. "BIA hand device" by United States Marine Corps is in the Public Domain

- **Air displacement plethysmography (ADP)** – This is a non-invasive, quick tool that does not take extensive training. It's more accurate but also more expensive than BIA. While a person sits inside an enclosed chamber (usually called a Bod Pod), changes in air pressure are used to determine the amount of air 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 9.3.5: Body composition measurement with *whole-body air displacement plethysmography (ADP) technology or BodPod.* "Body composition measurement with whole-body air displacement plethysmography(ADP) technology" by cosmed is licensed under CC BY-SA 3.0

- **Dual-energy X-ray absorptiometry (DXA)**. This method directs two low-dose X-ray beams through the body and determines the amount of energy absorbed from the beams. The amount of energy absorbed is dependent on the body's content of bone, lean tissue mass, and fat mass. Using standard mathematical formulas, fat content and bone density can be accurately estimated. Although this is one of the most accurate methods of measuring fat mass, it is expensive and mostly used in research. It also requires low doses of radiation to the subject being tested, and is not appropriate for pregnant women.



Figure 9.3.6: Dual-Energy X-ray Absorptiometry (DXA). “A Dual-energy X-ray absorptiometry (DEXA) scan” by Nick Smith is licensed under CC BY-SA 3.0

Keep in mind that body composition can be hard to measure accurately when using inexpensive and accessible techniques like skinfold testing and BIA. Your best bet is to pick one method and use that method over time to compare numbers and see how they change. Just don’t get too hung up on the actual number, as the accuracy will be questionable depending on the method chosen.

Measuring Fat Distribution

Total body fat is one predictor of health; another is how the fat is distributed in the body. The location of fat is important, because people who store fat more centrally (apple-shaped) have a higher risk for chronic disease—like cardiovascular disease and type 2 diabetes—compared 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.

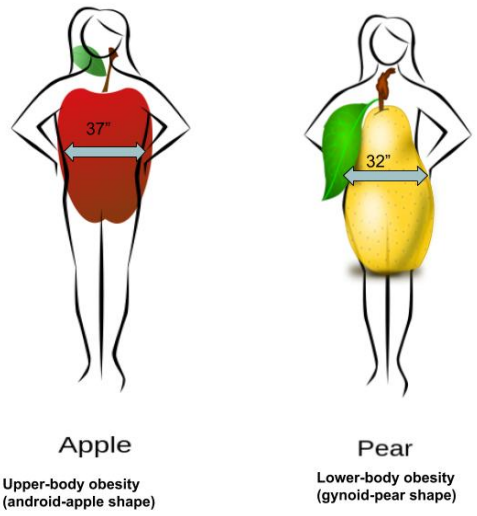


Figure 9.3.7: Fat can be located in the abdominal region (apple shape) or hips, thighs, and buttocks (pear shape). “Fat Distribution” by Allison Calabrese is licensed under CC BY 4.0

Body fat distribution can be measured by waist circumference and waist-to-hip ratio, both of which only require a measuring tape.

- **Waist circumference** is measured just above the hip bone, level with your belly button. Men with a waist circumference greater than 40 inches and women with a waist circumference greater than 35 inches are predicted to face greater health risks.

- **Waist-to-hip ratio** is calculated by measuring waist circumference and hip circumference (at its widest part) and dividing the two values. Abdominal obesity is defined by the World Health Organization as a waist-to-hip ratio above 0.90 for males and above 0.85 for females.

Indicators of Metabolic Health

Metabolic health refers to the body's ability to maintain normal homeostasis and effectively regulate measures like blood pressure, blood lipids, and blood glucose. It is assumed that when an individual is classified as overweight and obese, based on measurements of BMI and body fat composition and distribution, metabolic health is negatively impacted. However, some individuals that meet the criteria for obesity do not experience an increased risk of metabolic health.[7] These individuals are known as "***metabolically healthy obese***" ***(MHO).*** Metabolically healthy can be described as an absence of insulin resistance, type 2 diabetes, dyslipidemia, and hypertension.

In contrast, there are also individuals who are classified as a healthy weight (BMI < 25) but show an increased metabolic risk. These individuals are known as ***metabolically obese normal weight (MONW).***

These variations challenge the assumptions we hold about body fatness. It can not always be assumed that thinness equals healthy, and fatness equals unhealthy.

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9.4: Overweight and Underweight—What are the Risks?

As the previous section illustrated, energy balance is influenced by many factors. Whether an individual is in positive or negative energy balance ultimately influences the overall trend in whether that individual is normal weight, overweight, or underweight. While much of the focus in society is placed on concerns with being overweight or obese, both ends of the weight spectrum are associated with health risks, and being underweight can negatively impact health just as being overweight can. In fact, **research has shown a J-shaped association between mortality risk and BMI**, with greater risk for dying in underweight and obese populations and the lowest risk occurring in the normal BMI range. [1]

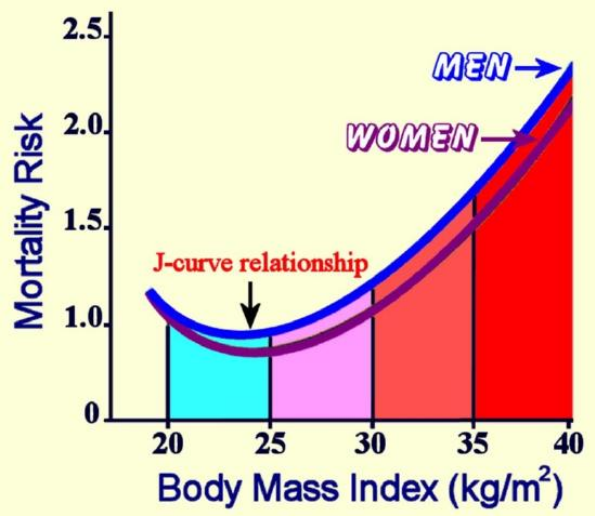


Figure 9.4.1: The relationship between body mass index and mortality forms a J-shaped curve, demonstrating higher rates of death associated with underweight and overweight/obese, with lowest rates of death associated with normal weight. "Relationship Between Body Mass Index (BMI) and Mortality " is in the Public Domain, CC0

What are the specific risks associated with being overweight or underweight? Let's take a closer look at each of these situations.

Health Risks of Being Overweight or Obese

The health consequences of too much body fat are numerous. 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.

According to the World Health Organization (WHO), there are more people worldwide who are overweight or obese than underweight, and an estimated 2.8 million adults die annually as a result of being overweight or obese. [2] As BMI increases over 25, the risks increase for several health conditions, [3] including:

- Heart disease
- Type 2 diabetes
- Hypertension
- Stroke
- Osteoarthritis
- Sleep apnea
- Some cancers (endometrial, breast, colon, kidney, gallbladder, liver)
- Depression and anxiety
- Difficulty with physical movement
- Lower quality of life

Childhood obesity is also a global health concern. In 2016 over 340 million children and adolescents and 41 million preschool children were overweight or obese. And obese children are more likely to become obese adults, develop diabetes and

cardiovascular disease at younger ages, and have an increased risk of premature death. [2]

Similar to other public health organizations, the WHO states that the main causes of the global obesity epidemic are increased intake of energy-dense foods and decreased physical activity associated with modernization, industrialization, and urbanization. The environmental changes that contribute to the dietary and physical activity patterns of the world today are associated with the lack of policies that address the obesity epidemic in the food and health industry, urban planning, agriculture, and education sectors. [2]

Economic and Societal Costs of Being Overweight and Obese

The economic burden of overweight and obesity has skyrocketed as obesity rates in the United States continue to climb. According to a recent report, direct health care costs due to overweight and obesity (money directly paid to treat the illness) exceed $480 billion and indirect health care costs (lost economic productivity due to absenteeism, lost wages, and reduced productivity) have surpassed $1.2 trillion. [4] On the individual level, people who are obese spend $3,429 more per year for medical care than people of healthy weight. [5]

Social and emotional consequences of being overweight or obese are no less real than economic costs. Individuals with obesity often face discrimination, lower wages, depression, anxiety, and lower quality of life. [3,6] Weight bias and discrimination are of particular concern for those who are overweight or obese. ***Weight bias*** is defined as "negative weight-related attitudes, beliefs, assumptions and judgments toward individuals who are overweight and obese," though this bias does extend to those who are underweight as well. [7]

Incidence of weight discrimination has increased by 66 percent since 1995 and occurs at rates similar to that of racial discrimination. [8] According to Rebecca Puhl, PhD, deputy director of the Rudd Center for Food Policy & Obesity at the University of Connecticut, "Bias, stigma, and discrimination due to weight are frequent experiences for many individuals with obesity, which have serious consequences for their personal and social well being and overall health." [9] Puhl has also noted that "about 40% of the general population reports that it has experienced some type of weight stigma—whether it be weight-based teasing, unfair treatment, or discrimination." [10] Individuals who are obese are often blamed for their disease and viewed as being lazy, stupid, ugly, and lacking in self-control or motivation. [11] This bias toward people with obesity is seen in many aspects of life, including the workplace, health care, social environments, and even the individual's own family.

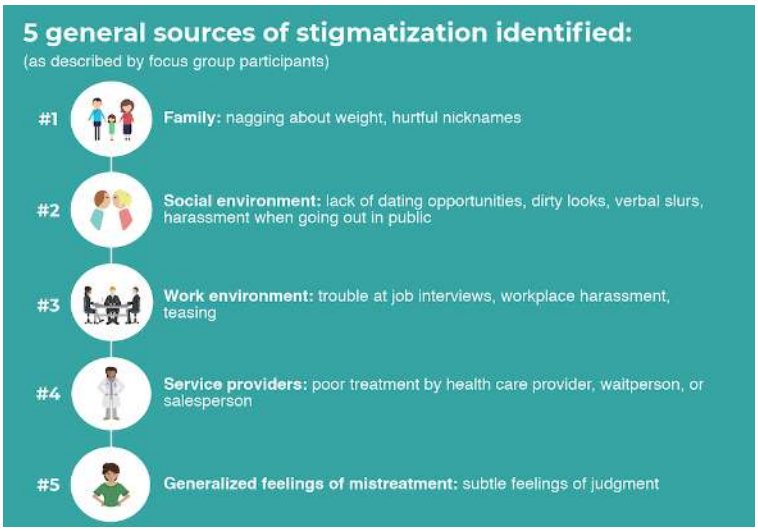


Figure 9.4.2: Common sources of weight stigmatization identified by individuals who are overweight or obese include families, social environments, work environments, and service providers, as well as generalized feelings of judgment from others. Source: Cossrow, N. H., Jeffery, R. W., & McGuire, M. T. (2001). Understanding weight stigmatization: A focus group study. Journal of nutrition education, 33(4), 208-214. "Sources of Stigmatization" by Heather Leonard is licensed under CC BY 4.0

Combating weight bias and discrimination will require change on many levels. Governments can include weight as a category covered in anti-discrimination laws. Anti-bullying efforts at the school level should include policies on harassment and bullying related to weight. Health care should include reimbursement for obesity treatment, and weight bias training should be required for health care providers. And education and awareness about weight bias on an individual level will help change negative attitudes toward overweight and obesity. [9,12]



Video 9.4.1: " Weight of the Nation: Stigma—The Human Cost of Obesity" by HBO Docs, YouTube (May 14, 2012), 18:54. This is an excellent video to help increase awareness of weight stigma, humanizing the pain and damage caused by weight bias and discrimination.



Figure 9.4.3: "Stop Bullying" by jstn-1-7_pe is licensed under CC BY 2.0

Health Risks of Being Underweight

The 2015–2016 National Health and Nutrition Examination Survey (NHANES) estimated that 1.5 percent of adults and 3.0 percent of children and adolescents in the United States are underweight. [13,14] Underweight individuals represent a small portion of Americans, yet the health risks associated with being underweight are an important part of the discussion on nutrition and health.

Being underweight is linked to nutritional deficiencies, especially iron-deficiency anemia, and to other problems such as delayed wound healing, hormonal abnormalities, increased susceptibility to infection, and increased risk of some chronic diseases such as osteoporosis. In children, being underweight can stunt growth. The most common underlying cause of underweight in America is inadequate nutrition. Other causes are wasting diseases (cancer, multiple sclerosis, tuberculosis) and eating disorders. People with wasting diseases are encouraged to seek nutritional counseling, as a healthy diet greatly affects survival and improves responses to disease treatments.

Eating Disorders

The National Institute of Mental Health (NIMH) defines eating disorders as " serious and sometimes fatal illnesses that cause severe disturbances to a person's eating behavior s." [15] 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. [16]



Figure 9.4.4: "woman on scale" by Luxstorm is licensed under CC BY 2.0

Eating disorders that result in underweight affect about eight million Americans (seven million women and one million men). And eating disorders have the second highest mortality rate of mental illnesses, outranked only by opioid addiction. [17] Prevention and proper treatment of eating disorders must involve a multi-faceted approach, including physical, emotional, and social issues related to each individual's needs. [18]

Anorexia Nervosa

Anorexia nervosa, more often referred to as "anorexia," is a psychiatric illness in which a person obsesses about their weight and about the food that they eat. Anorexia results in extreme nutrient inadequacy and eventually organ malfunction. Anorexia is relatively rare—the NIMH reports that 0.9 percent of females and 0.3 percent of males will have anorexia at some point in their lifetime, but it is an extreme example of how an unbalanced diet can affect health. [15]

Anorexia frequently manifests during adolescence, although it may emerge much later in adulthood as well. People with anorexia consume, on average, fewer than 1,000 calories per day and exercise excessively. They are in a tremendous caloric imbalance. Moreover, some may participate in binge eating, self-induced vomiting, and purging with laxatives or enemas. The exact causes of anorexia are not completely known, but many things contribute to its development including economic status, as it is most prevalent in high-income families. It is a genetic disease and is often passed from one generation to the next. Complications during fetal development and abnormalities in the brain, endocrine system, and immune system may all contribute to the development of this illness.

The primary signs of anorexia are fear of being overweight, extreme dieting, an unusual perception of body image, and depression. The secondary signs and symptoms of anorexia are all related to the caloric and nutrient deficiencies of the unbalanced diet and include excessive weight loss , a multitude of skin abnormalities, diarrhea, cavities and tooth loss, osteoporosis, and liver, kidney, and heart failure. There is no physical test that can be used to diagnose anorexia and distinguish it from other mental illnesses. Therefore, a correct diagnosis involves eliminating other mental illnesses, hormonal imbalances, and nervous system abnormalities. Treatment of any mental illness involves not only the individual, but also family, friends, and a psychiatric counselor. Treating anorexia often involves a registered dietitian, who helps to provide dietary solutions that are adjusted over time. The goals of treatment for anorexia are to restore a healthy body weight and significantly reduce the weight obsession and behaviors associated with the eating disorder. Relapse to an unbalanced diet is high. Many people do recover from anorexia; however, most continue to have a lower-than-normal body weight for the rest of their lives .

Bulimia

Bulimia, like anorexia, is a psychiatric illness that can have severe health consequences. The NIMH reports that 0.5 percent of females and 0.1 percent of males will have bulimia at some point in their lifetime. [15]

Bulimia is characterized by episodes of eating large amounts of food followed by purging, which is accomplished by vomiting and with the use of laxatives and diuretics. Unlike people with anorexia, those with bulimia often have a normal weight, making the disorder more difficult to detect and diagnose. Bulimia is characterized by signs similar to anorexia such as fear of being overweight, extreme dieting, and bouts of excessive exercise. Secondary signs and symptoms include gastric reflux, severe erosion of tooth enamel, dehydration, electrolyte imbalances, lacerations in the mouth from vomiting, and peptic ulcers. Repeated damage to the esophagus puts people with bulimia at an increased risk for esophageal cancer. The disorder is also highly genetic, linked to depression and anxiety disorders, and most commonly occurs in adolescent girls and young women. Treatment often involves antidepressant medications and, like anorexia, has better results when both the family and the individual with the disorder participate in nutritional and psychiatric counseling .



Figure 9.4.5: This photo shows the erosion on the lower teeth caused by bulimia. For comparison, the upper teeth were restored with porcelain veneers. "Oral Manifestation of Bulimia" by Jeffrey Dorfman is licensed under CC BY-SA 3.0

Binge-Eating Disorder

Similar to those who experience anorexia and bulimia, people with binge-eating disorder have lost control over their eating. Binge-eating disorder was only recently classified as a distinct psychiatric illness, becoming formally recognized as a diagnosable eating disorder in 2013. People with ***binge-eating disorder*** will periodically overeat to the extreme, but their loss of control over eating is not followed by fasting, purging, or compulsive exercise. As a result, people with this disorder are often overweight or obese, and their chronic disease risks are those linked to having an abnormally high body weight such as hypertension, cardiovascular disease, and Type 2 diabetes. Additionally, they often experience guilt, shame, and depression. Binge-eating disorder is commonly associated with depression and anxiety disorders. According to the NIMH, binge-eating disorder is more prevalent than anorexia and bulimia, and affects almost 3 percent of individuals at some point during their lifetime. [15] Treatment often involves antidepressant medication as well as nutritional and psychiatric counseling.

Orthorexia

Orthorexia 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. [19] While focusing on a healthy diet isn't inherently a bad thing, in situations of ***orthorexia***, the individual takes the emphasis of healthy eating, or "clean" eating, to the extreme, so much so that it becomes a fixation, putting their health at risk. [19]

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]

If you think you or someone close to you might have an eating disorder and you want to learn more or find resources for help, check out these organizations and links.

National Eating Disorders Association -- Help & Support

National Association of Anorexia Nervosa and Associated Disorders -- Eating Disorders Helpline: **(888)-375-7767**

Eating Disorder Hope

Attributions:

- University of Hawai‘i at Mānoa Food Science and Human Nutrition Program, “ Undernutrition, Overnutrition, and Malnutrition ,” CC BY-NC 4.0

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9.5: Obesity Epidemic- Causes and Solutions

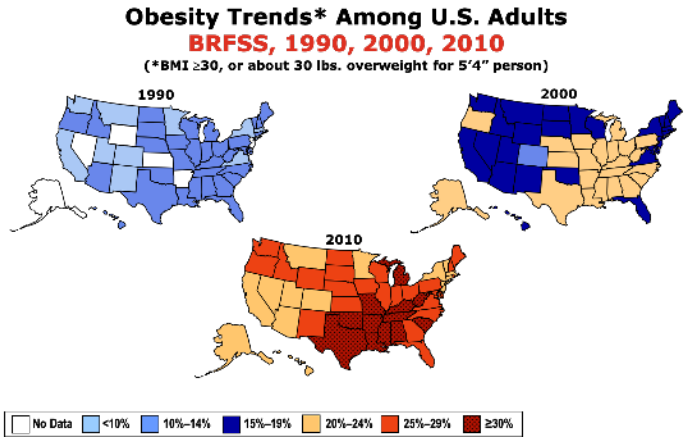


Figure 9.5.1: Each year since 1990, the CDC has published maps of the United States in which states are color-coded based on the percentage of their population estimated to be obese. The maps show a clear increase in the prevalence of obesity between 1990 and 2010. "Obesity Trends Among U.S. Adults, 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

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. are obese.

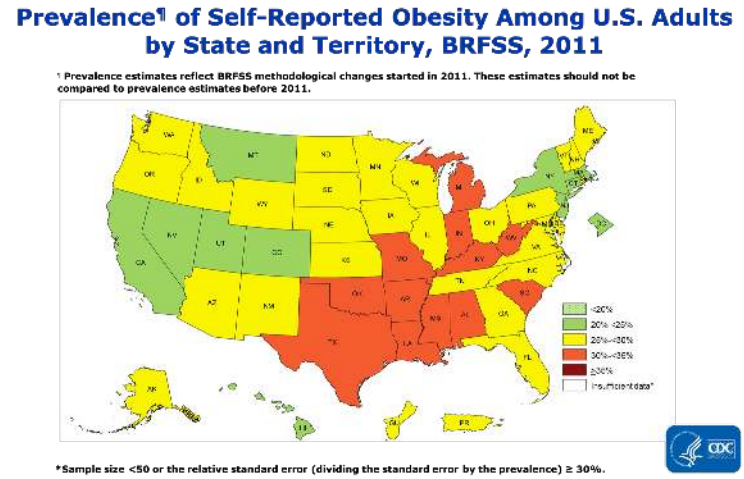
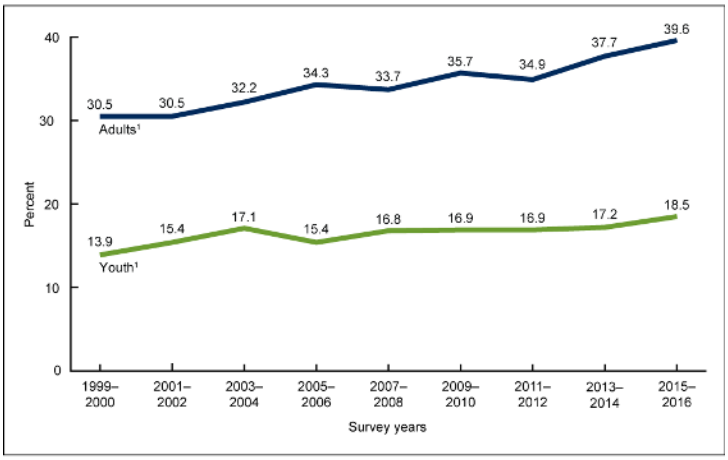


Figure 9.5.2: The prevalence of obesity among U.S. adults has continued to rise between 2011 and 2018. "Prevalence of self-reported obesity among U.S. adults in 2011 and 2018" by Division of Nutrition, Physical Activity, and Obesity, National Center for Chronic Disease Prevention and Health Promotion , Centers for Disease Control and Prevention is in the Public Domain

These trends are unmistakable, and they're not just occurring in adults. Childhood obesity has seen similar increases over the last few decades—perhaps an even greater concern as the metabolic and health effects of carrying too much weight can be compounded over a person's entire lifetime.

Figure 5. Trends in obesity prevalence among adults aged 20 and over (age adjusted) and youth aged 2–19 years: United States, 1999–2000 through 2015–2016



¹Significant increasing linear trend from 1999–2000 through 2015–2016.
NOTES: All estimates for adults are age adjusted by the direct method to the 2000 U.S. census population using the age groups 20–39, 40–59, and 60 and over.
Access data table for Figure 5 at: https://www.cdc.gov/nchs/data/databriefs/db288_table.pdf#5.
SOURCE: NCHS, National Health and Nutrition Examination Survey, 1999–2016.

Figure 9.5.3: etween 1999 and 2016, the prevalence of obesity in both children and adults has risen steadily. "Trends in obesity prevalence" by National Center for Health Statistics is in the Public Domain

While obesity is a problem across the United States, it affects some groups of people more than others. Based on 2015-2016 data, obesity rates are higher among Hispanic (47 percent) and Black adults (47 percent) compared with white adults (38 percent). Non-Hispanic Asians have the lowest obesity rate (13 percent). And overall, people who are college-educated and have a higher income are less likely to be obese.[2] These health disparities point to the importance of looking at social context when examining causes and solutions. Not everyone has the same opportunity for good health, or an equal ability to make changes to their circumstances, because of factors like poverty and longstanding inequities in how resources are invested in communities. These factors are called "***social determinants of health.***"[3]

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 .[4] Globally, among children aged 5 to 19 years old, the rate of overweight increased from 10.3 percent in 2000 to 18.4 percent in 2018. Previously, overweight and obesity mainly affected high-income countries, but some of the most dramatic increases in childhood overweight over the last decade have been in low income countries, such as those in Africa and South Asia, corresponding to a greater availability of inexpensive, processed foods.[5]

Despite the gravity of the problem, no country has yet been able to implement policies that have reversed the trend and brought about a decrease in obesity. This represents "one of the biggest population health failures of our time," wrote an international group of researchers in the journal The Lancet in 2019.[6] The World Health Organization has set a target of stopping the rise of obesity by 2025. Doing so requires understanding what is causing the obesity epidemic; it is only when these causes are addressed that change can start to occur.

Causes of the Obesity Epidemic

If obesity was an infectious disease sweeping the globe, affecting billions of people's health, longevity, and productivity, we surely would have addressed it by now. Researchers and pharmaceutical companies would have worked furiously to develop vaccines and

medicines to prevent and cure this disease. But the causes of obesity are much more complex than a single bacteria or virus, and solving this problem means recognizing and addressing a multitude of factors that lead to weight gain in a population.

Behavior

At its core, rising obesity is caused by a chronic shift towards positive energy balance—consuming more energy or calories than one expends each day, leading to an often gradual but persistent increase in body weight. People often assume that this is an individual problem, that those who weigh more 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. While behavior patterns such as diet and exercise can certainly impact a person's risk of developing obesity (as we'll cover later in this chapter), the environments where we live also have a big impact on our behavior and can make it much harder to maintain energy balance.

Environment

Many of us live in what researchers and public health experts call "***obesogenic environments.***" That is, the ways in which our neighborhoods are built and our lives are structured influence our physical activity and food intake to encourage weight gain .[7] Human physiology and metabolism evolved in a world where obtaining enough food for survival required significant energy investment in hunting or gathering—very different from today's world where more people earn their living in sedentary occupations. From household chores, to workplace productivity, to daily transportation, getting things done requires fewer calories than it did in past generations.



Figure 9.5.4: 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. Elements of obesogenic environment: "wocintech" by WOCinTech Cha is licensed under CC BY 2.0 ; "Perfect timing" by Tamara Menzi , Unsplash is in the Public Domain, CC0 ; "Vending machines" by Purchase College Library is licensed under CC BY-NC 2.0

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 fears about neighborhood safety limit kids' ability to get out and play after the school day is over. Our towns and cities are built more for cars than for walking or biking. We can't turn back the clock on human progress, and finding a way to stay healthy in obesogenic environments is a significant challenge.

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 calorie-dense (and less nutrient-dense) and more heavily processed, with amounts of sugar, fat, and salt optimized to make us want to eat more, compared with home-cooked food. In addition, portion sizes at restaurants, especially fast food chains, have increased over the decades, and people are eating at restaurants more and cooking at home less.

Poverty and Food Insecurity

Living in poverty usually means living in a more obesogenic environment. Consider the fact that some of the poorest neighborhoods in the United States—with some of the highest rates of obesity—are often not safe or pleasant places to walk, play, or exercise. They may have busy traffic and polluted air, and they may lack sidewalks, green spaces, and playgrounds. A person living in this type of neighborhood will find it much more challenging to get adequate physical activity compared with someone living in a neighborhood where it's safe to walk to school or work, play at a park, ride a bike, or go for a run.

In addition, poor neighborhoods often lack a grocery store where people can purchase fresh fruits and vegetables and basic ingredients necessary for cooking at home. Such areas are called "***food deserts***"—where healthy foods simply aren't available or easily accessible.

Another concept useful in discussions of obesity risk is "food insecurity." ***Food security*** means "access by all people at all times to enough food for an active, healthy life."[8] ***Food insecurity*** means an inability to consistently obtain adequate food. It may seem counter-intuitive, but in the United States, food insecurity is linked to obesity. That is, people who have difficulty obtaining enough food are more likely to become obese and 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.[3]

Genetics

What about genetics? While it's true that our genes can influence our susceptibility to becoming obese, researchers say they can't be a cause of the obesity epidemic. Genes take many generations to evolve, and the obesity epidemic has occurred over just the last 40 to 50 years—only a few generations. When our grandparents were children, they were much less likely to become obese than our own children. That's not because their genes were different, but rather because they grew up in a different environment. However, it is true that a person's genes can influence their susceptibility to becoming obese in this obesogenic environment, and obesity is more prevalent in some families. A person's genetic make-up can make it more difficult to maintain energy balance in an obesogenic environment, because certain genes may make you feel more hungry or slow your energy expenditure.[2]

Solutions to the Obesity Epidemic

Given the multiple causes of obesity, solving this problem will also require many solutions at different levels. Because obesity affects people over the lifespan and is difficult to reverse, the focus of many of these efforts is prevention, starting as early as the first years of life. We'll discuss individual weight management strategies later in this chapter. Here, we'll review some strategies happening in schools, communities, and at the state and federal levels.

Support Healthy Dietary Patterns

Interventions that support healthy dietary patterns, especially among people more vulnerable because of food insecurity or poverty, may reduce obesity. In some cases, studies have shown that they have an impact, and in other cases, it's too soon to know. Here are some examples:

- Implement and support better nutrition standards for childcare, schools, hospitals, and worksites.[9]
- Limit marketing of processed foods, especially ads targeted towards children.
- Provide incentives for supermarkets or farmers markets to establish businesses in underserved areas.[9]



Figure 9.5.5: Farmers markets can expand healthy food options for neighborhoods and build connections between consumers and local farmers. Figure 9.21. Farmers markets. "group of people standing near vegetables" by Megan Markham is in the Public Domain, CC0 ; "Veggies at Corvallis Farmers Market" by Friends of Family Farmers is licensed under CC BY-ND 2.0

- Place nutrition and calorie content on restaurant and fast food menus to raise awareness of food choices.[9] Beginning in 2018, as part of the Affordable Care Act, chain restaurants with more than 20 locations were required to add calorie information to their menus, and some had already done so voluntarily. There isn't yet enough research to say whether having this information improves customers' choices; some studies show an effect and others don't.[10] Many factors influence people's decisions, and the type of restaurant, customer needs, and menu presentation all likely matter. For example, some studies show that health-conscious consumers choose lower calorie menu items when presented with nutrition information, but people with food insecurity may understandably choose higher calorie items to get more "bang for their buck".[11] Research has also shown that adding interpretative images—like a stoplight image labeling menu choices as green or red as shorthand for high or low nutrient density—can help. And a 2018 study found that when calorie counts are on the left side of English-language menus, people order lower-calorie menu items. Putting calorie counts on the right side of the menu (as is more common) doesn't have this effect, likely because the English language is read from left to right.[12] Some studies have also found that restaurants that implement menu labeling offer lower-calorie and more nutrient-dense options, indicating that menu labeling may push restaurants to look more closely at the food they serve.[10,13]



Figure 9.5.6: 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? Menu labeling. "Ballpark Calorie Counting" by Kevin Harber is licensed under CC BY-NC-ND 2.0

- Increase access to food assistance programs and align them with nutrition recommendations. For example, in 2009, the U.S. Department of Agriculture revised the food packages for the Women, Infants, and Children (WIC) program to better align with the Dietary Guidelines for Americans. The new packages emphasized more fruits, vegetables, whole grains, and low-fat dairy and decreased the availability of juice. After this change, there was a decrease in the obesity rate of children in the WIC program. Similar progress may be made by increasing access to the Supplemental Nutrition Assistance Program (SNAP) in order to reduce food insecurity. Many farmers' markets now accept SNAP benefits for the purchase of fresh fruit and vegetables.[3]
- Tax sugary drinks, such as soda and sports drinks, which contribute significant empty calories to the U.S. diet and are associated with childhood obesity. Local taxes on soda and other sugary drinks are often controversial, and soda companies lobby to prevent them from passing. However, early research in U.S. cities with soda taxes show that they do work to decrease soda consumption.[3] 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.[14]

Support Greater Physical Activity

Increasing physical activity increases the energy expended during the day. This can help maintain energy balance, thus preventing weight gain. It may also help to shift a person into negative energy balance and facilitate weight loss if needed. But simply adding an exercise session—a run or a trip to the gym, say—often doesn't shift energy balance (though it's certainly good for health). Why? Exercise can increase hunger, and there's only so many calories a person can burn in 30 or 60 minutes. That's why it's also important to look for opportunities for non-exercise activity thermogenesis (NEAT); that is, find ways to increase movement throughout the day.

- Prioritize physical education and recess time in schools. In addition to helping kids stay healthy, movement also helps them learn.
- Make neighborhoods safer and more accessible for walking, cycling, and playing.
- When safe, encourage kids to walk or bike to school.
- Build family and community activities around physical activity, such as trips to the park, walks together, and community walking and exercise groups.
- Facilitate more movement in the workday by encouraging walking meetings, movement breaks, and treadmill desks.

- Find ways to move that are enjoyable to you and fit your life. Yard work, walking your dog, playing tag with your kids, and going out dancing all count!



Figure 9.5.7: There are lots of ways to increase physical activity, including walking to work, playing with friends, and going for a bike ride. Increasing physical activity. "Early bird" by Jorge Vasconez is in the Public Domain, CC0 ; "boy running to the future" by Rafaela Biazi is in the Public Domain, CC0 ; "people riding bicycles inside bicycle lane beside skyscraper" by Steinar Engeland is in the Public Domain, CC0



Video 9.5.1: "James Levine: 'I Came Alive as a Person'" by NOVA's Secret Life of Scientists and Engineers, YouTube (April 24, 2014), 3:04 minutes. This short video explains some of the research on NEAT and efforts to increase it in our lives.



Video 9.5.2: "The Weight of the Nation: Poverty and Obesity" by HBO Docs, YouTube (May 14, 2012), 24:05 minutes.

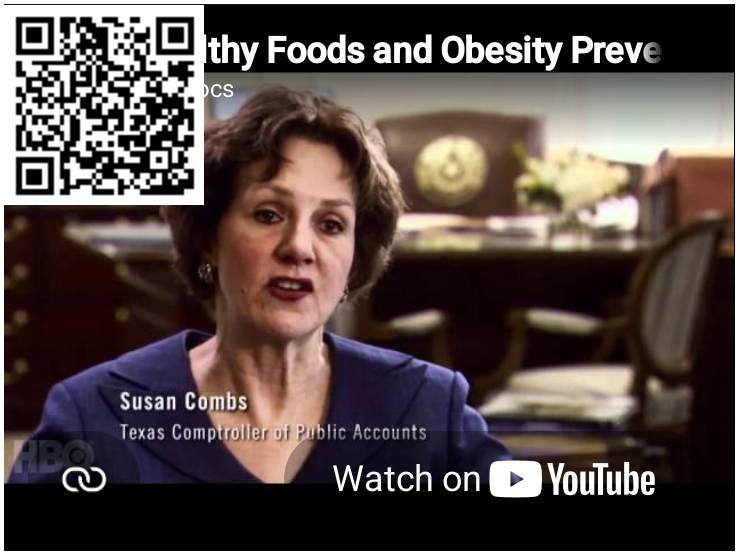


Figure 9.5.1: "The Weight of the Nation: Healthy Foods and Obesity Prevention" by HBO Docs, YouTube (May 14, 2012), 31:11 minutes. These segments from the HBO documentary series, "The Weight of the Nation," explore some of the causes and potential solutions for obesity.

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9.6: Best Practices For Weight Management

With over 70 percent of Americans currently overweight or obese, it isn't surprising that many individuals report engaging in weight management efforts. [1] In fact, a 2019 report from a national survey on current trends in weight loss attempts and strategies found that 42 percent of adults in the United States had recently attempted to lose weight, primarily through reduced food consumption and exercise. [2] In this unit we examine the best practices for weight management based on the body of evidence from many years of scientific research.



Figure 9.6.1: "Individuals with Obesity" by Obesity Canada is licensed under CC BY-ND 2.0

Biology Behind the Challenge of Weight Loss

We have just considered the gravity of the obesity problem in the U.S. and worldwide. How is the U.S. combating its weight problem on a national level, and have the approaches been successful? Successful weight loss is defined as individuals intentionally losing at least 10 percent of their body weight and keeping it off for at least one year. [3] Results from some lifestyle intervention studies suggest that most individuals are not successful at long-term weight loss. Yet an evaluation of successful weight loss involving more than fourteen thousand participants published in the November 2011 issue of the International Journal of Obesity estimated that more than one in six Americans (17 percent) who were overweight or obese were successful at both achieving and maintaining a significant level of weight loss. [4] While this estimate is more promising than other studies suggest, it still raises the question: Why is achieving long-term weight loss so difficult? Much of the explanation lies in understanding the biology of weight loss.

Weight loss has often been viewed as a simple formula: energy in versus energy out. If you consume more calories than you expend, you gain weight. If you expend more calories than you consume, you lose weight. This is the general principle of energy balance, as discussed earlier in this unit, and this principle gives foundation to the basic premise of weight management.

However, the body is more complex than a simple formula. And much like many functions within the body, weight is tightly regulated. In order to prevent perpetual weight loss or weight gain every time environmental or behavioral factors change, mechanisms within the body adjust to help normalize weight at a steady point. [5] But our obesogenic environment often promotes behaviors that encourage excessive caloric intake and lower energy expenditure, leading to a higher steady weight over time. When an individual focuses on losing weight, active weight loss efforts often yield initial weight loss. But those same mechanisms that work to maintain a steady weight also kick in during periods of weight loss to help the body defend the original weight. [5] The body recognizes weight loss as a threat to survival, lowering basal metabolic rate to preserve calories and protect against starvation. Additionally, as someone loses weight, there is less physical mass to the body that has to be moved from place to place throughout the day, resulting in fewer calories burned through physical movement and activity, and less metabolically active tissue using calories for fuel throughout the day.

Biological differences in individual metabolism may also impact weight loss success. Researchers have found that some individuals have a “thrifty” metabolism, meaning that they have a lower metabolic rate and expend significantly fewer calories when in a fasting (or calorie-restricted) state, common in weight loss efforts. This results in a lower level of weight loss. In contrast, individuals with a “spendthrift” metabolism tend to have a higher metabolic rate in a fasting state, burning more calories and thus yielding bigger weight loss results. [6] According to researcher Martin Reinhardt, M.D., “The results corroborate the idea that some people who are obese may have to work harder to lose weight due to metabolic differences.” [7]

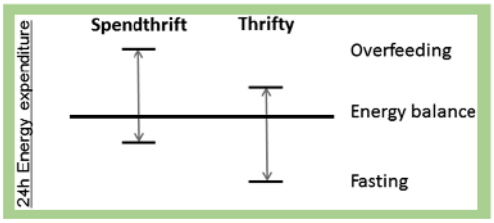


Figure 9.6.2: Illustration of the concept of spendthrift and thrifty metabolisms, characterized by their response to overfeeding and fasting. Thrifty vs spendthrift genes. Fig. 1. Reinhardt, M., Thearle, M. S., Ibrahim, M., Hohenadel, M. G., Bogardus, C., Krakoff, J., & Votruba, S. B. (2015). A human thrifty phenotype associated with less weight loss during caloric restriction. Diabetes, 64(8), 2859-2867.

To add to the challenge of metabolic differences, research also suggests that changes in hormone levels due to weight loss may impact the body’s ability to maintain a lower weight. Decreases in thyroid hormones that regulate metabolism, as well as changes in hormones such as leptin and insulin that affect satiety levels, contribute to the challenge of maintaining a lower weight after initial weight loss occurs. [5,8] In individuals maintaining a 10% or greater weight loss, all of these changes combine to account for an estimated decrease of 300-400 calories in energy expenditure per day beyond what is expected due to the change in body composition alone. [8] These biological factors and their influence on weight are discussed further in the below video.



VIDEO: “ The Quest to Understand the Biology of Weight Loss ,” by HBO Docs, YouTube (May 14, 2012), 22:52 minutes.

Evidence-Based Approaches to Weight Loss

In spite of the challenges imposed by biological processes in the body, there is significant evidence to suggest that successful weight loss and maintenance is possible. There are many approaches when considering options for weight loss, and no single treatment is right for everyone. In fact, while following a lower-calorie healthy eating plan is often the first approach to weight loss, research shows that there is no single dietary strategy that is superior to others. [9,10] For example, **a recent trial, called the DIETFITS study, followed participants on either a low-fat or low-carbohydrate diet for one year and found no significant difference in weight loss between study groups.** And both dietary strategies produced a range of weight loss results, with some

participants losing over 60 pounds and others gaining 20 pounds over the course of the year, suggesting that what works for one individual may produce varying results in others. [1]

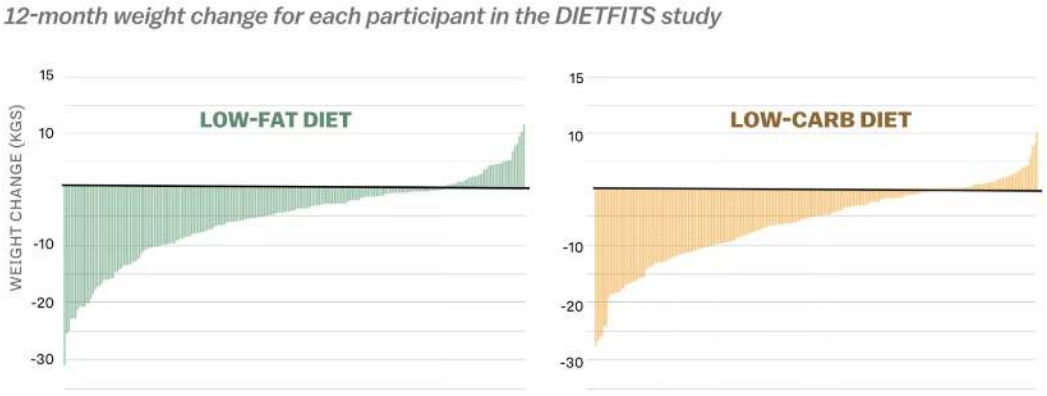


Figure 9.25. Results from the DIETFITS study show that regardless of the type of diet followed, participants experienced a similar wide range of changes in weight.

To learn more about the DIETFITS study, check out the following video.



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VIDEO: " Stanford's Christopher Gardner Tackles the Low-Carb vs. Low-Fat Question ." by Stanford Medicine, YouTube (February 19, 2018), 4:08 minutes.

The National Weight Control Registry (NWCR) has tracked over ten thousand people who have been successful in losing at least 30 pounds and maintaining this weight loss for at least one year. Their research findings show that 98 percent of participants in the registry modified their food intake, and 94 percent increased their physical activity, mainly by walking. [11]

Although there were a great variety of approaches taken by NWCR members to achieve successful weight loss, most have reported that their approach involved adhering to a low-calorie, low-fat diet and doing high levels of activity (about one hour of exercise per day). Moreover, most members eat breakfast every day, watch fewer than ten hours of television per week, and weigh themselves at least once per week. About half of them lost weight on their own, and the other half used some type of weight-loss program. [11]

In most scientific studies, successful weight loss is accomplished only by changing the diet and increasing physical activity together. Doing one without the other limits the amount of weight lost and the length of time that weight loss is sustained. [12]

Evidence-Based Dietary Recommendations

The 2015 Dietary Guidelines for Americans offers specific, evidence-based recommendations for dietary changes aimed at keeping calorie intake in balance with physical activity, which is key for weight management. [13] These recommendations include following a healthy eating pattern that accounts for all foods and beverages within an appropriate calorie level, including the following:

- A variety of vegetables from all of the subgroups—dark green, red and orange, legumes (beans and peas), starchy, etc.
- Fruits, especially whole fruits
- Grains, at least half of which are whole grains
- Fat-free or low-fat dairy, including milk, yogurt, cheese, and/or fortified soy beverages
- A variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products
- Oils

A healthy eating pattern limits:

- Saturated fats and trans fats
- Added sugars
- Sodium

Key quantitative recommendations are provided for several components of the diet that should be limited. These components are of particular public health concern in the U.S., and the specified limits can help individuals achieve healthy eating patterns within calorie limits. [13]

- Consume less than 10 percent of calories per day from added sugars
- Consume less than 10 percent of calories per day from saturated fats
- Consume less than 2,300 milligrams (mg) per day of sodium

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

While these guidelines establish basic recommendations for dietary intake across all food groups, most Americans fall short of achieving these recommendations. Figure 9.26 shows how Americans are falling short of meeting the recommendations for vegetables, fruit, dairy, and oils, and consume well over the recommendations for added sugars, saturated fat, and sodium.

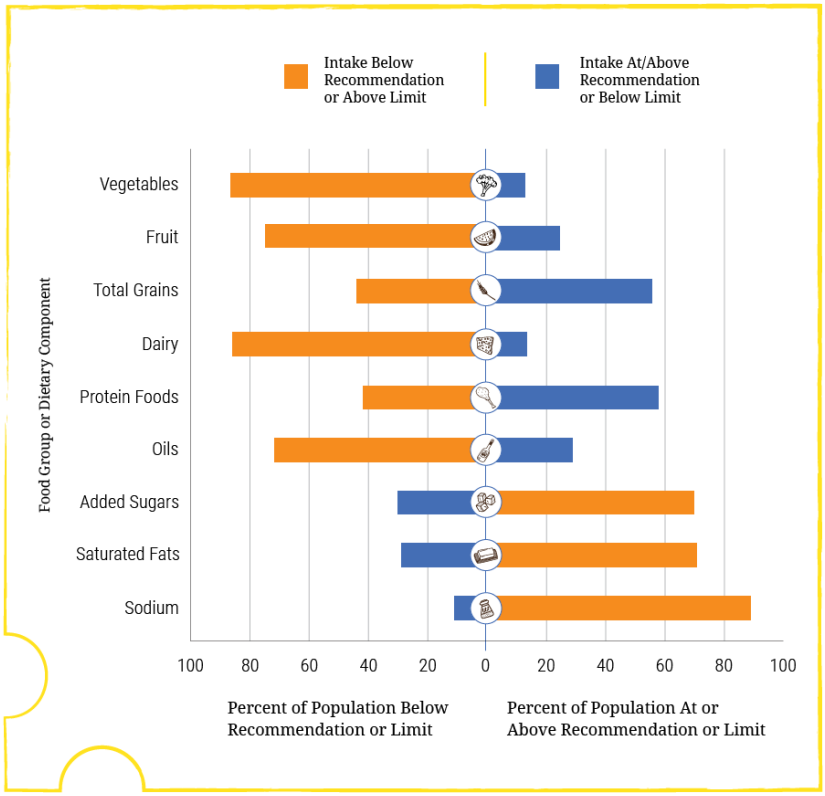


Figure 9.26. This bar graph indicates the percentage of the U.S. population ages 1 year and older with intakes below the recommendation or above the limit for different food groups and dietary components.

Evidence-Based Physical Activity Recommendations

The other part of the energy balance equation is physical activity. The Dietary Guidelines are complemented by the 2018 Physical Activity Guidelines for Americans, issued by the Department of Health and Human Services (HHS) in an effort to provide evidence-based guidelines for appropriate physical activity levels. These guidelines provide recommendations to Americans aged three and older about how to improve health and reduce chronic disease risk through physical activity. Increased physical activity has been found to lower the risk of heart disease, stroke, high blood pressure, Type 2 diabetes, colon, breast, and lung cancer, falls and fractures, depression, and early death. Increased physical activity not only reduces disease risk, but also improves overall health by increasing cardiovascular and muscular fitness, increasing bone density and strength, improving cognitive function, and assisting in weight loss and weight maintenance. [14]

The key guidelines for adults include the following:

- Adults should move more and sit less throughout the day. Some physical activity is better than none. Adults who sit less and do any amount of moderate-to-vigorous physical activity gain some health benefits.
- For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) per week of moderate-intensity aerobic activity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) per week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity .
- Preferably, aerobic activity should be spread throughout the week.
- Engaging in physical activity beyond the equivalent of 300 minutes (5 hours) of moderate-intensity physical activity per week can result in additional health benefits and may help with weight loss and weight loss maintenance.
- Adults should also do muscle-strengthening activities of at least moderate intensity that involve all major muscle groups on 2 or more days per week, as these activities provide additional health benefits . Exercises such as push-ups, sit-ups, squats, and lifting weights are all examples of muscle-strengthening activities.

The 2018 Physical Activity Guidelines broadly classify moderate physical activities as those when you "can talk, but not sing, during the activity" and vigorous activities as those when you "cannot say more than a few words without pausing for a breath." [14] Despite the indisputable benefits of regular physical activity, a 2018 report from the American Heart Association estimates that 8 out of 10 Americans do not meet these guidelines. [2]

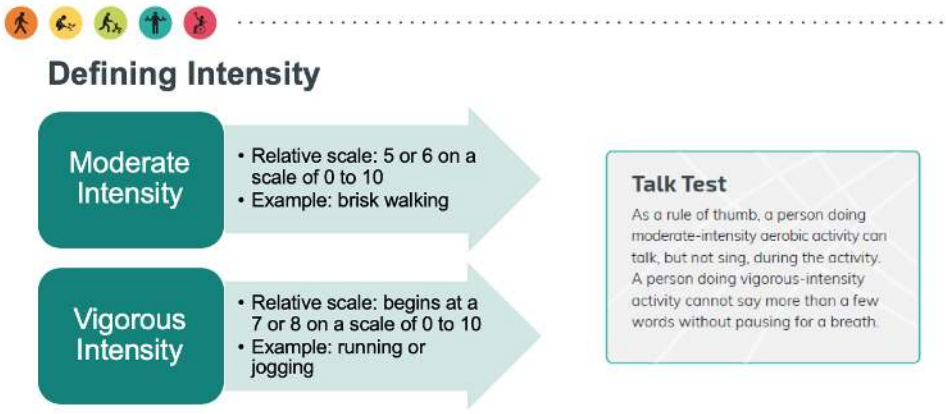


Figure 9.27. The 2018 Physical Activity Guidelines' definition of moderate-intensity and vigorous-intensity exercise.

Given the number of Americans that are falling short on both nutrition and physical activity recommendations, it is easy to see that these two areas of behavior are of primary interest in improving the health and weight of our nation.

Evidence-Based Behavioral Recommendations

Behavioral weight loss interventions have been described as approaches "used to help individuals develop a set of skills to achieve a healthier weight. It is more than helping people to decide what to change; it is helping them identify how to change." [15] 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. [16] 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. [17]

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.** [17,18] The behavioral intervention team often includes primary care clinicians, dietitians , psychologists, behavioral therapists, exercise physiologists, and lifestyle coaches. [17] 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. [17] 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.[1 6]

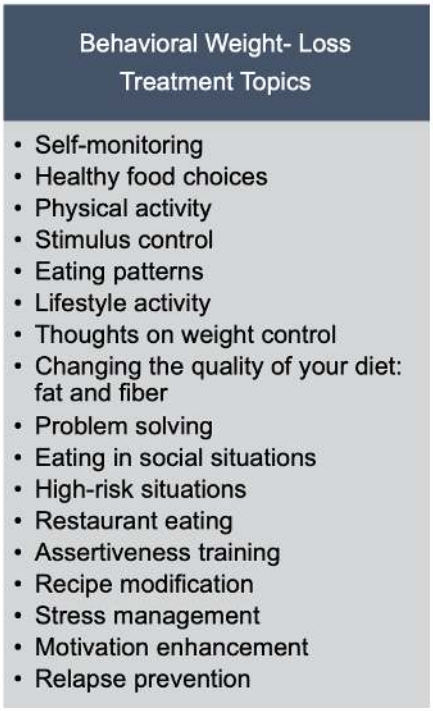


Figure 9.28. Common topics included in behavioral interventions for weight loss, adapted from Smith, C. E., & Wing, R. R. (2000). New directions in behavioral weight-loss programs. Diabetes Spectrum, 13(3), 142-148.

Pharmacotherapy and Bariatric Surgery

In some situations, lifestyle changes in diet, exercise, and behavior modification are not enough to produce meaningful levels of weight loss, and the use of medications may be considered to improve weight loss outcomes. The use of medications is recommended in conjunction with, and not in place of, lifestyle changes. Medications are typically considered for individuals with a BMI over 30, or BMI over 27 with at least one coexisting condition, such as heart disease, type 2 diabetes, or hypertension. Only medications approved by the FDA for weight loss should be used . [19] Over-the-counter weight loss supplements are not monitored by the FDA and are not recommended due to safety concerns.

Surgical interventions may be appropriate for individuals 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. [19]

Non-Diet Approaches

In addition to weight management approaches that focus on the energy balance equation through dietary changes, physical activity programs, and behavioral interventions, there is a growing movement for non-diet approaches for a healthier mentality toward weight, food, and body image. These approaches focus on establishing healthier relationships with food and more body acceptance and positivity regardless of shape and size. Many of these programs seek to normalize relationships with food, make eating an

enjoyable experience focused on well-being rather than dieting, do away with shame or guilt often associated with failed weight loss efforts, and promote respect and inclusivity for all people regardless of weight or size. Mindful eating or intuitive eating are common components of these approaches.



One of these approaches, the ***Satter Eating Competence Model***, is based on four components: eating attitudes, food acceptance, regulation of food intake and body weight, and management of the eating context. According to Ellyn Satter, a registered dietitian and family therapist and the founder of the model, competent eaters are "confident, comfortable, and flexible with eating and are matter-of-fact and reliable about getting enough to eat of enjoyable and nourishing food." [20] This approach enhances "the importance of eating by making it positive, joyful, and intrinsically rewarding." [20] This model emphasizes that by developing a healthier relationship with food, individuals will yield the following benefits: [21]

- Have better diets
- Feel more positive about food and eating
- Have better overall health
- Have the same or lower BMI
- Sleep better
- Be more active
- Have better physical self-acceptance
- Be more trusting of themselves and others

Health at Every Size (HAES) is another movement started by the Association for Size Diversity and Health (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. [22] 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.



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VIDEO: " Why Dieting Doesn't Usually Work ," from TED, 12:30 minutes.

Self-Check

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Attributions:

- University of Hawai'i at Mānoa Food Science and Human Nutrition Program, " Dietary, Behavioral, and Physical Activity Recommendations for Weight Management ," CC BY-NC 4.0

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- Figure 9.24. Thrifty vs spendthrift genes. Fig. 1. Reinhardt, M., Thearle, M. S., Ibrahim, M., Hohenadel, M. G., Bogardus, C., Krakoff, J., & Votruba, S. B. (2015). A human thrifty phenotype associated with less weight loss during caloric restriction. Diabetes, 64(8), 2859-2867.
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CHAPTER OVERVIEW

10: Vitamins and Minerals Overview

10.1: Introduction to Vitamins and Minerals
10.2: Classification of Vitamins and Minerals
10.3: Sources of Vitamins and Minerals
10.4: Dietary Supplements
10.5: Water-Soluble Vitamins Summary
10.6: Fat-Soluble Vitamins Summary
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10.9: EDIT Research Highlight - Vitamin-like Compounds

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10.1: Introduction to Vitamins and Minerals

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 10.1.1: "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 chapters 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 minerals, and we'll consider the role of dietary supplements in meeting our vitamin and mineral requirements. Then, we'll spend the remainder of this chapter looking at summaries of major functions of vitamins and minerals, where we find them in food, and what happens if we consume too little or too much of each. Many of the vitamins and minerals will be covered in more detail during the next chapters, which explore the vitamins and minerals that are needed for the function of various systems and structures in the body.

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10.2: Classification of Vitamins and Minerals

Vitamins and minerals 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 deficiency or toxicity when too little or too much is consumed. After we review the classifications for vitamins and minerals, we will examine key vitamins and minerals based on their similar functions to further highlight the importance of how these micronutrients work together.



Figure 10.2.1: "Variety of Fruits in Tray" photo by Danielle MacInnes on Unsplash (license information)

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.

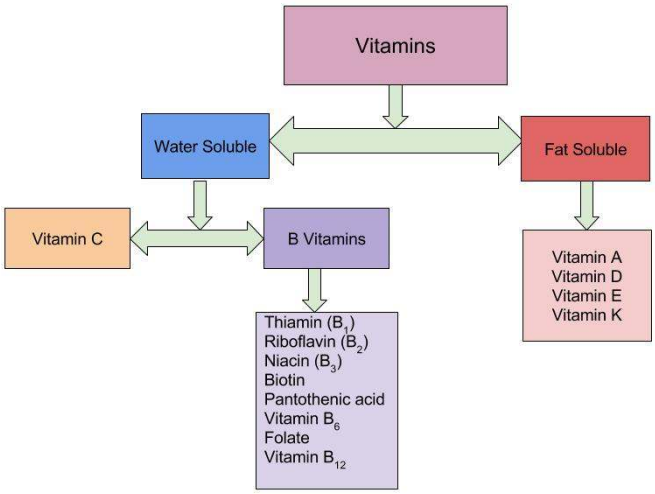


Figure 10.2.2: "Classification of vitamins as water-soluble or fat-soluble" by Allison Calabrese is licensed under CC BY 4.0

One major difference between water-soluble and fat-soluble vitamins is 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.

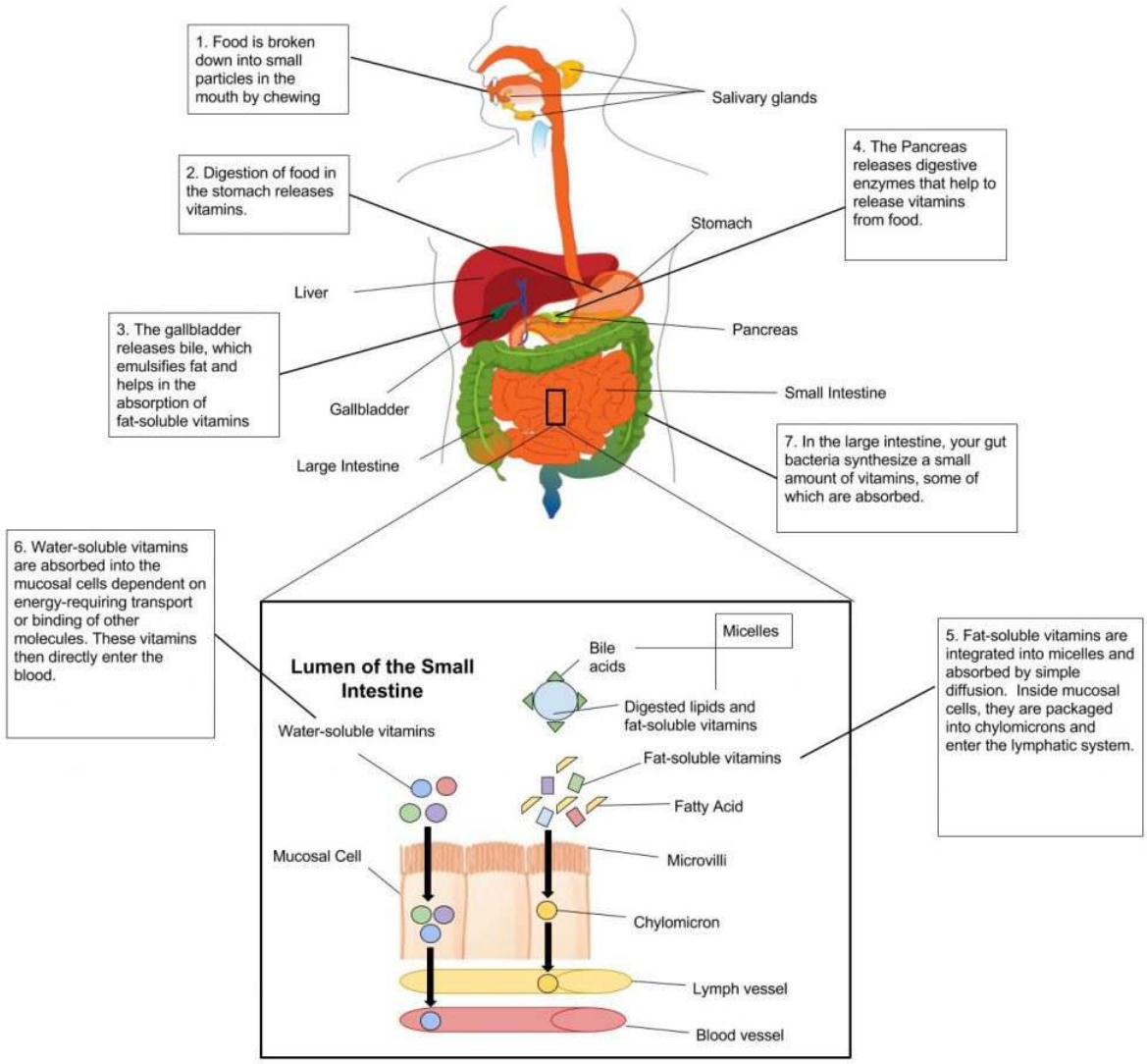


Figure 10.2.3: "Absorption of Fat-Soluble and Water-Soluble Vitamins" by Allison Calabrese is licensed under CC BY 4.0

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

There is limited storage capacity in the body for water-soluble vitamins, thus making it important to consume these vitamins on a daily basis. Deficiency of water-soluble vitamins is more common than fat-soluble vitamin deficiency because of this lack of storage. That also means toxicity of water-soluble vitamins is rare. Because of their solubility in water, intake of these vitamins in amounts above what is needed by the body can, to some extent, be excreted in the urine, leading to a lower risk of toxicity. 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 10.2.1: "Characteristics of fat-soluble and water-soluble vitamins" by Heather Leonard is licensed under CC BY 4.0

Minerals

Similarly to vitamins, minerals are micronutrients that are essential to human health and can be obtained in our diet from different types of food. Minerals are abundant in our everyday lives. From the soil in your front yard to the jewelry you wear on your body, we interact with minerals constantly. ***Minerals*** are inorganic elements in their simplest form, originating from the Earth. They can't be broken down or used as an energy source, but like vitamins, 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]



Figure 10.2.4: "Green-leafed Vegetables" photo by Kenan Kitchen on Unsplash (license information)

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.

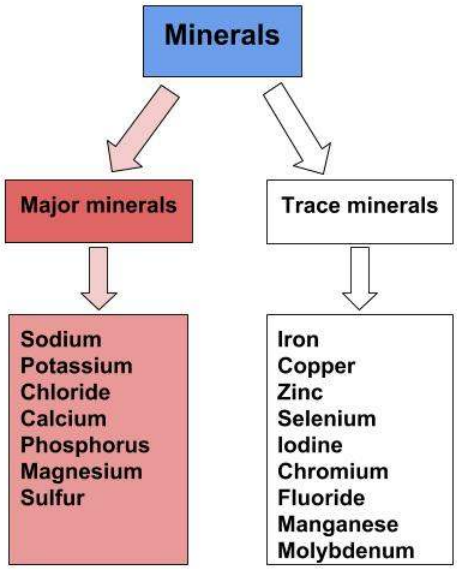


Figure 10.2.5: "Classification of major and trace minerals" by Allison Calabrese is licensed under CC BY 4.0

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

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

- Minerals are generally better absorbed from animal-based foods. Plant-based foods often contain compounds that can bind to minerals and inhibit their absorption (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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10.3: Sources of Vitamins and Minerals

Vitamins and Minerals in Food

Eating a variety of foods from all food groups is the best way to ensure you are getting all the micronutrients needed for a healthy diet. Each food group lends itself to specific vitamins and minerals. Keep in mind that whole foods (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.

Food Group	Vitamins Provided	Minerals Provided
	• Thiamin • Riboflavin • Niacin • Folate	• Iron • Magnesium • Selenium
	• Vitamin A (in the form of beta-carotene) • Vitamin C • Vitamin K • Folate	• Potassium • Magnesium
	• Vitamin A (in the form of beta-carotene) • Vitamin C • Folate	• Potassium
	• Vitamin A • Vitamin D • Vitamin E • Niacin • Thiamin • Riboflavin • Vitamin B_6	• Iron • Zinc • Magnesium
	• Vitamin A (fortified) • vitamin D (fortified) • Vitamin B_{12}	• Calcium • Potassium • Phosphorus

Table 10.3.1: "Common vitamins and minerals found in each food group" by Heather Leonard, reformatted and edited by Christine Bisson, is licensed under CC BY 4.0 using MyPlate graphics from USDA's Center for Nutrition Policy and Promotion in the Public Domain

Effects of Processing on Nutrient Content in Foods

The nutrient content of foods is typically highest when foods are allowed to ripen on the plant, allowing the plant to fully develop the nutrients and phytochemicals 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.

Method of Processing	Effect on Nutrient Retention	How to Minimize Nutrient Loss
Air exposure and time	Enzymes present in foods and exposure to air can destroy nutrients, because as soon as the food is harvested, 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.

Table 10.3.2: The effects of processing on nutrient retention.[1] "The effects of processing on nutrient retention" by Heather Leonard is licensed under CC BY 4.0; data from Devi, R. (2005). Food processing and impact on nutrition. Research Scholar, Department of Economics, Kurukshetra University, Kurukshetra, Haryana, India. Retrieved from http://saspjournals.com/wp-content/uploads/2015/08/SJAVS-24A304-311.pdf

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.

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.



Figure 10.3.1: “Fresh carrots” photo by Jonathan Pielmayer on Unsplash (license information)

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

Vitamins Made by Intestinal Bacteria

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

- Bacteria that colonize the large intestine can synthesize one form of vitamin K, although the total amount made in the large intestine is not clear.[5]
- Gut bacteria are also able to make all B vitamins, though the amount synthesized of each vitamin is dependent on the composition of each individual’s microbiome.[6,7] Dietary choices (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]



Figure 10.3.2: “Yogurt and berries” photo by Maëliss Demaison on Unsplash (license information)

References:

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10.4: Dietary Supplements

By now you know that a balanced, nutritious diet is important for good health. But you may also wonder if your diet is adequate, or if you could benefit from taking a vitamin or mineral supplement. You may also be curious about other supplements that claim to help you lose weight, build muscle, ease joint pain, or help build good bacteria in your gut.



Figure 10.4.1: Woman holding probiotic capsule photo by Daily Nouri on Unsplash (license information)

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

- 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 beforethey 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.



Figure 10.4.2: Supplement photo by Angel Sinigersky on Unsplash (license information)

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 10.4.3: 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] "USP Verification Mark" by USP is used with permission.

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 and serious health problems."

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10.5: Water-Soluble Vitamins Summary

Water-Soluble Vitamins

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Vitamin	Food Sources	Recommended Intake for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk of Deficiency	Toxicity Symptoms	Tolerable Upper Intake Level (UL)

Vitamin C (ascorbic acid) Vitamin C Fact Sheet	Orange juice, grapefruit juice, strawberries, tomato, sweet red pepper Vitamin C in Foods	75-90 mg/day	Antioxidant, collagen synthesis, hormone and neurotransmitter synthesis	Scurvy, bleeding gums, joint pain, poor wound healing, Kidney Stones, GI distress, diarrhea 2000 mg/day
Thiamin	Pork, enriched and whole grains, fish, legumes Thiamin in Foods	1.1-1.2 mg/day	Coenzyme: assists in glucose metabolism, RNA, DNA, and ATP synthesis	BAN Not determined

in (B1) Thiamin Fact Sheet			eoe rl p iio :cr fst a, e t od il gd ue er , a cd ou nl ft us s, ie oa nt , i mn og vd ei ms eo nr td ie mr ps a i r m e n t , s w e l l i n g , h e

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Riboflavin (B2) Beef liver, enriched breakfast cereals, yogurt, steak, mushrooms, almonds, eggs Riboflavin in Foods Riboflavin Fact Sheet	1.1-1.3 mg/day	Coenzyme: assists in glucose, fat and carbohydrate metabolism, electron carrier, other B vitamins are dependent on	Arriboflavinosis: dry scaly skin, mouth inflammation	Not determined Not reported

				tionandsores,sorethroat,itchyeyes,lightsensitivity

Niacin (B3) Niacin Fact Sheet	Meat, poultry, fish, peanuts, enriched grains Niacin in Foods	14-16 NE/day	Coenzyme: assists in glucose, fat, and protein metabolism, electron carrier	Pellagra: diarrhea, dermatitis, dementia, death Nausea, rash, liver toxicity, glucose intolerance Alcoholism	35 mg/day from fortified foods and supplements

Pantothenic Acid (B5)	Sunflower seeds, fish, dairy products, widespread in foods Pantothenic Acid in Foods	5 mg/day	Coenzyme: assists in glucose, fat, and protein metabolism, cholesterol and neurotransmitter synthesis	Muscle numbness and Fatigue, nausea, vomiting, irritability Not determined
B6 (Pyrid	Meat, poultry, fish, legumes, nuts Vitamin B6 in Foods	1.3-1.7 mg/day	Coenzyme; assists in amino-acid synthesis, glycogneolysis, neurotransmitter and hemoglobin synthesis	Muscle convulsions, headache, nausea, vomiting 100 mg/day

oxine) Vitamin B6 Fact Sheet			acacknesss, dermatitis, mouth sores, fatigue, confusion

Biotin Biotin Fact Sheet	Egg yolks, fish, pork, nuts and seeds Biotin in Foods	30 mcg/day	Coenzyme; assists in glucose, fat, and protein metabolism, amino-acid synthesis	Muscle weakness, dermatitis, loss of appetite, nausea, depression, hallucinations, paresthesia, hair thinning, red scaly rash around eyes, nose, genitals, and mouth	None reported	Not determined
Folate Folate Fact Sheet	Leafy green vegetables, enriched grains, orange juice Folate in Foods	400 mcg/day	Coenzyme; amino acid synthesis, RNA, DNA, and red blood cell synthesis	Diarrhea, irritability, mouth sores, poor growth, megaloblastic anemia, weakness, fatigue, headache, decreased appetite, nausea, gastrointestinal disturbances	1000 mcg/day from fortified foods and supplements

ate Fact Sheet			omf ueitnc h, isaeol nrcc eoy sh, ocl oi nc fs usion, anemia, neural-tubedefects
B12 (cob	Meats, poultry, fish Vitamin B12 in Foods	2.4 mcg/day	Coenzyme; fat and protein catabolism, folate function, red-blood-cell synthesis	MVNueosgncaellnresew, p	Not determined

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Vitamin B12 Fact Sheet

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			ects
CEgg yolk, wheat, meat, **h**fish, synthesis in the body **o** **l** Choline in Foods **i** **n** **e** Choline Fact Sheet	425-550 mg/day	Synthesis of neurotransmitters and cell membranes, lipid transport	NNL3.5 g/day ooi nnv -ee alcoholic fatty liver disease, muscled amage, inte rdamage, excessive weating, hypotension

			r f e r e d b r a i n d e v e l o p m e n t i n f e t u s

Table 10.5.1: Water-Soluble Vitamins from Human Nutrition, 2020 Edition by Draper, Revilla, & Titchenal, and edited by Christine Bisson to include links to National Institutes of Health - Office of Dietary Supplements - Consumer Fact Sheets and Nutrient Content of Foods from USDA - Agricultural Research Service - Food Data Central - Component Search, is licensed CC BY-NC-SA

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10.6: Fat-Soluble Vitamins Summary

Fat-Soluble Vitamins

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Vitamin	Food Sources	Recommended Intake for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk of Deficiency	Toxicity Symptoms	Tolerable Upper Intake Level (UL)
Vitamin A (retinol, retinal, retinoic acid,carotene, beta-carotene) Vitamin A Fact Sheet	Retinol: beef and chicken liver, skim milk, whole milk, cheddar cheese; Carotenoids: pumpkin, carrots, squash, collards, peas Vitamin A in Foods	700-900 mcg/day	Antioxidant, vision, cell differentiation, reproduction, immune function	Xerophthalmia, night blindness, eye infections; poor growth, dry skin, impaired immune function	People living in poverty (especially infants and children), premature infants, pregnant and lactating women people who consume low-fat or low-protein diets	Hypervitaminosis A: Dry, itchy skin, hair loss, liver damage, joint pain, fractures, birth defects, swelling of the brain	3000 mcg/day
Vitamin D Vitamin D Fact Sheet	Swordfish, salmon, tuna, orange juice (fortified), milk (fortified), sardines, egg, synthesis from sunlight Vitamin D in Foods	600-800 IU/day (15-20 mcg/day)	Absorption and regulation of calcium and phosphorus, maintenance of bone	Rickets in children: abnormal growth, misshapen bones, bowed legs, soft bones; osteomalacia in adults	Breastfed infants, older adults people with limited sun exposure, people with dark skin	Calcium deposits in soft tissues, damage to the heart, blood vessels, and kidneys	4000 IU/day (100 mcg/day)
Vitamin E Vitamin E Fact Sheet	Sunflower seeds, almonds, hazelnuts,peanuts Vitamin E in Foods	15 mg/day	Antioxidant, protects cell membranes	Broken red blood cells, nerve damage	People with poor fat absorption, premature infants	Inhibition of vitamin K clotting factors	1000 mcg/day from supplemental sources
Vitamin K Vitamin K Fact Sheet	Vegetable oils, leafy greens, synthesis by intestinal bacteria Vitamin K in Foods	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	Not determined

Figure 10.6.1: Fat-Soluble Vitamins from Human Nutrition, 2020 Edition by Draper, Revilla, & Titchenal, and edited by Christine Bisson to include links to National Institutes of Health - Office of Dietary Supplements - Consumer Fact Sheets and Nutrient Content of Foods from USDA - Agricultural Research Service - Food Data Central - Component Search, is licensed CC BY-NC-SA

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10.7: Major Minerals Summary

Major Minerals

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Micronutrient	Food Sources	Recommended Intakes for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk for Deficiency	Toxicity Symptoms	Tolerable Upper Intake Level (UL)
Calcium Calcium Fact Sheet	Yogurt, cheese, sardines, milk, orange juice, turnip Calcium in Foods	1,000 mg/day	Component of mineralized bone, provides structure and microarchitecture	Increased risk of osteoporosis	Postmenopausal women, those who are lactose intolerant, or vegan	Kidney stones	2,500 mg
Phosphorus Phosphorus Fact Sheet	Salmon, yogurt, turkey, chicken, beef, lentils Phosphorus in Foods	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 Magnesium Fact Sheet	Whole grains and legumes, almonds, cashews, hazelnuts, beets, collards, and kelp Magnesium in Foods	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 Sulfur in Foods	None specified	Structure of some vitamins and amino acids, acid-base balance	None when protein needs are met	None	None	Not determined
Sodium	Processed foods, table salt, pork, chicken Sodium in Foods	< 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

Micronutrient	Food Sources	Recommended Intakes for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk for Deficiency	Toxicity Symptoms	Tolerable Upper Intake Level (UL)
Potassium Potassium Fact Sheet	Fruits, vegetables, legumes, whole grains, milk Potassium in Foods	4700 mg/day	Major positive intracellular ion, nerve transmission, muscle contraction, fluid balance	Irregular heartbeat, muscle cramps	People consuming diets high in processed meats, those with vomiting or diarrhea	Abnormal heartbeat	Not determined
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

Figure 10.7.1: Major Minerals from Human Nutrition, 2020 Edition by Draper, Revilla, & Titchenal, and edited by Christine Bisson to include links to National Institutes of Health - Office of Dietary Supplements - Consumer Fact Sheets and Nutrient Content of Foods from USDA - Agricultural Research Service - Food Data Central - Component Search, is licensed CC BY-NC-SA

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10.8: Trace Minerals Summary

Trace Minerals

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Micronutrient	Food Sources	Recommended Intakes for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk for Deficiency	Toxicity Symptoms	Tolerable Upper Intake Level (UL)
Iron Iron Fact Sheet	Red meat, egg yolks, dark leafy vegetables, dried fruit, iron-fortified foods Iron in 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 Copper Fact Sheet	Nuts, seeds, whole grains, seafood Copper in Foods	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 Zinc Fact Sheet	Oysters, wheat germ, pumpkin seeds, squash,, beans, sesame seeds, tahini, beef, lamb Zinc in Foods	8-11 mg/day	Assists in energy production, protein, RNA and DNA synthesis; required for hemoglobin synthesis	Growth retardation in children, hair loss, diarrhea, skin sores, loss of appetite, weight loss	Vegetarians, older adults	Depressed immune function	40 mg/day
Selenium Selenium Fact Sheet	Meat, seafood, eggs, nuts Selenium in Foods	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 Iodine Fact Sheet	Iodized salt, seaweed, dairy products Iodine in Foods	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 Chromium Fact Sheet	Meats, nuts and whole grain Chromium in Foods	25-35 mcg/day	Assists insulin in carbohydrate, lipid and protein metabolism	abnormal glucose metabolism	Malnourished children	None	Not determined

Micronutrient	Food Sources	Recommended Intakes for Adults	Major Functions	Deficiency Diseases and Symptoms	Groups at Risk for Deficiency	Toxicity Symptoms	Tolerable Upper Intake Level (UL)
Fluoride Fluoride Fact Sheet	Fluoridated water, foods prepared in fluoridated water, seafood Fluoride in Foods	3-4 mg/day	Component of mineralized bone, provides structure and microarchitecture, stimulates new bone growth	Increased risk of dental caries	Populations with non fluoridated water	Fluorosis mottled teeth, kidney damage	10 mg/day
Manganese Manganese Fact Sheet	Legumes, nuts, leafy green vegetables Manganese in Foods	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 Molybdenum Fact Sheet	Milk, grains, legumes Molybdenum in Foods	45 mcg/day	Cofactor for a number of enzymes	Unknown	None	Arthritis, joint inflammation	2 mg/day

Figure 10.8.1: Trace Minerals from Human Nutrition, 2020 Edition by Draper, Revilla, & Titchenal, and edited by Christine Bisson to include links to National Institutes of Health - Office of Dietary Supplements - Consumer Fact Sheets and Nutrient Content of Foods from USDA - Agricultural Research Service - Food Data Central - Component Search, is licensed CC BY-NC-SA

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10.9: EDIT Research Highlight - Vitamin-like Compounds

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... In the following publication... 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

APA citation

Further evaluation

To evaluate this publication further, it might help to...

References

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11: Water and Electrolytes

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11.1: Introduction to Fluids and Electrolytes

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 water in your body 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. These minerals are classified as **electrolytes**, which are minerals that have an electric charge. Electrolytes are found in blood, cells, and tissues throughout the body. They perform vital functions such as regulating fluid balance, moving nutrients into cells, removing wastes from cells, and contributing to the function of the heart, brain, and nerves.



Figure 11.1.1: Image by Baudolino from Pixabay / Pixabay License

One mechanism to help ensure the body maintains water balance is thirst. Thirst is the result of your body's physiology telling your brain to initiate the thought to take a drink. Sensory proteins detect when your mouth is dry, your blood volume too low, or blood electrolyte concentrations too high and send signals to the brain stimulating the conscious feeling to drink.

In this chapter we will discuss the importance and functions of fluid and electrolyte balance in the human body, the consequences of getting too much or too little of water and electrolytes, the best dietary sources of these nutrients, and healthier beverage choices.

Attributions

Alice Callahan, Heather Leonard, & Tamberly Powell, Instructors (Nutrition) at Lane Community College, Sourced from OpenOregon

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11.2: 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 11.2.1: 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 (H2O) 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 11.2.2). 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.

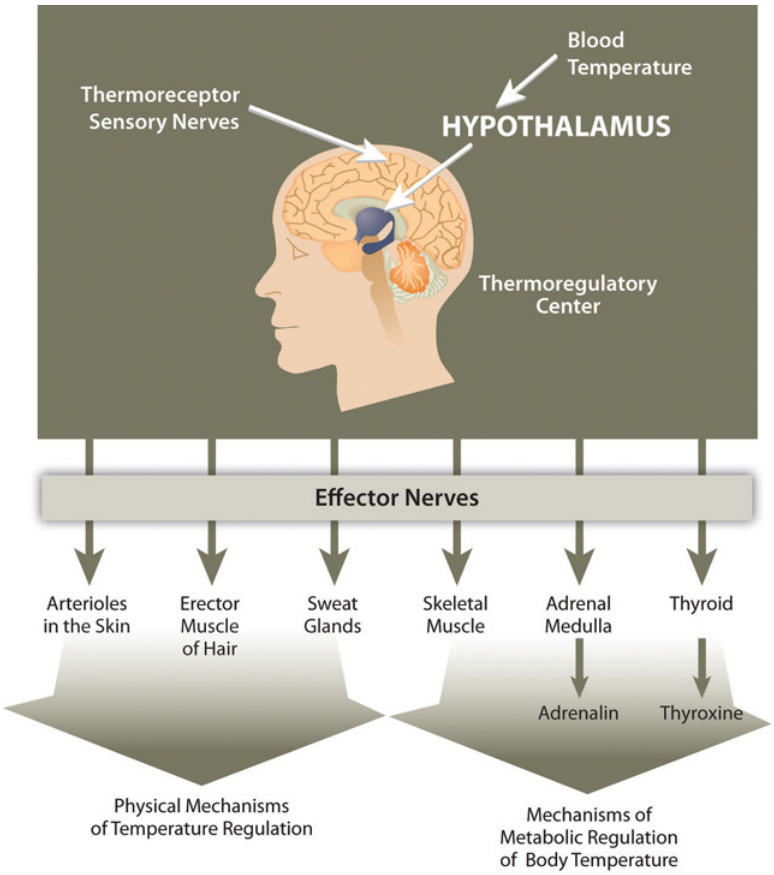


Figure 11.2.2: Thermoregulatory Center. Thermoregulation is the ability of an organism to maintain body temperature despite changing environmental temperatures.

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11.3: Water- Sources and Choices

Learning Objectives

- Distinguish between various sources of water in the diet.

Water is critical to human life. The complex process of how it is distributed and moved in the body, its role in maintaining fluid balance and composition, along with the daily fluid intake goals will be the focus of this unit. 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 11.3.1.

Table 11.3.1: 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 11.3.2). 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 11.3.2: 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 11.3.1). In fact, the treatment of drinking water is touted as one of the top public-health achievements of the last century.

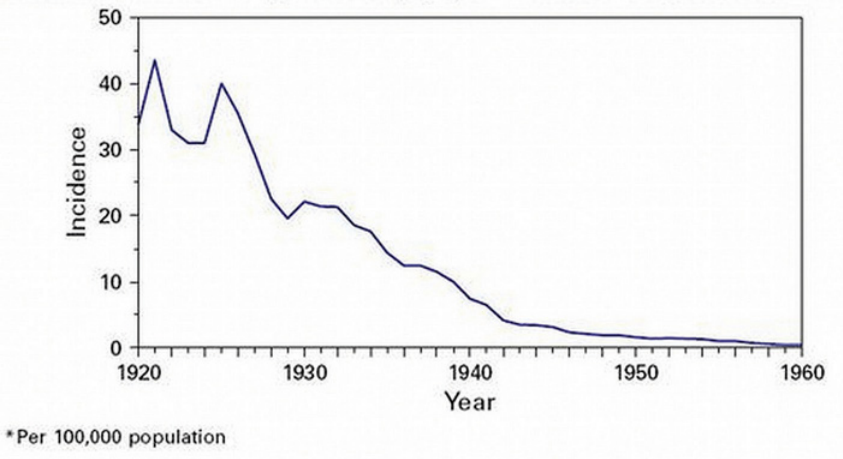


Figure 11.3.1: Deadly Water-borne Illnesses In United States. Deadly water-borne illnesses decreased to almost nonexistent levels in the United States after the implementation of water disinfection methods. Source: Image credit Robert Tauxe. Drinking Water Week. Centers for Disease Control and Prevention. 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.



Video 11.3.1: "The Story of Bottled Water" by The Story of Stuff Project; 8:04 minutes.

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11.4: Popular Beverage Choices

Learning Objectives

- List the pros and cons of consuming fluids in the form of several popular beverages.

Caffeine

Caffeine is a deriviative of a chemical compound 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. 130–200 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 11.4.1 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 11.4.1: 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

Beverage/Food	Milligrams
Full Throttle (16 oz.)	144
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.

Health Benefits

The most renowned effects of caffeine on the body are increased alertness and delay of fatigue and sleep. How does caffeine stimulate the brain? Caffeine is chemically similar to a chemical in our brains (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.

Tools for Change

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 11.4.1: Photo by Jeremy Ricketts on unsplash.com / CC0

There is scientific evidence supporting that higher consumption of caffeine, mostly in the form of coffee, substantially reduces the risk for developing Type 2 diabetes and 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]

Health Consequences

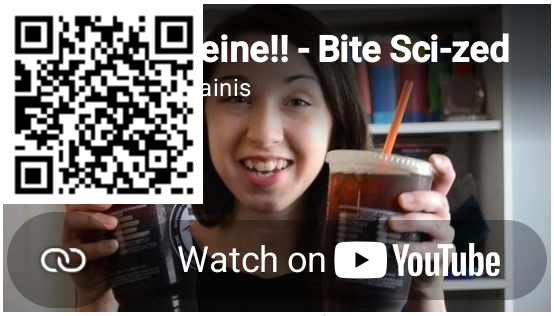
The acute adverse health effects of caffeine ingestion are anxiety, shakiness, and sleep deprivation. On a more chronic basis, some scientific reports suggest that higher caffeine intake is linked to negative effects on heart health and increased cardiovascular disease; although at this point most data 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]

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.

The Caffeine 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. Thus, caffeinated beverages are considered a source of hydration similar to water.



Video 11.4.1: "Caffeine Bite-SCIzed" by Alex Dainis, from TED Education; 4 minutes, 14 seconds.

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.

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11.5: Overview of Fluid and Electrolyte Balance

Water is made up of 2 hydrogen atoms and 1 oxygen atom. A human body is made up of mostly water. An adult consists of about 37 to 42 liters of water, or about eighty pounds. Fortunately, humans have compartmentalized tissues; otherwise we might just look like a water balloon!

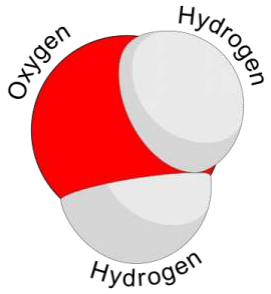


Figure 11.5.1: The Water Molecule. "Water Molecule" by Chris Martin / Public Domain

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.

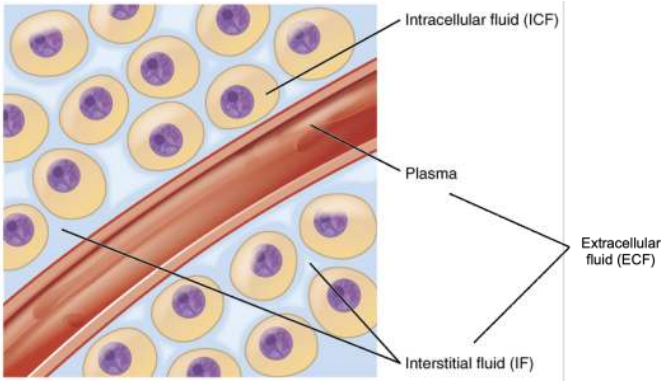


Figure 11.5.1: *Fluid compartments in the human body. The intracellular fluid (ICF) is the fluid within cells. The extracellular fluid (ECF) includes both the blood plasma and the interstitial fluid (IF) between the cells.* "Fluid Compartments in the Human Body" by J. Gordon Betts, Kelly A. Young, James 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

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.

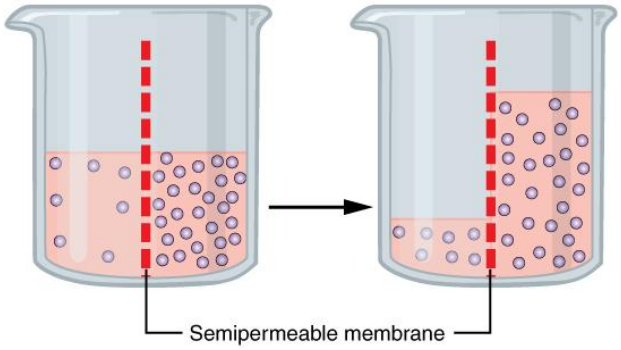


Figure 11.5.2: Osmosis is the diffusion of water through a semipermeable membrane towards higher solute concentration. If a membrane is permeable to water but not a solute, water will equalize its own concentration by diffusing to the side of lower water concentration (and thus the side of higher solute concentration). In the beaker on the left, the solution on the right side of the membrane is more concentrated with solutes; therefore, water diffuses to the right side of the beaker to equalize its concentration. Figure 8.7. "Osmosis" by OpenStax is licensed under CC BY 4.0

To maintain water and electrolyte balance, cells control the movement of electrolytes across their membranes, and water follows the electrolytes by osmosis. The health of the cell depends on proper fluid and electrolyte balance. If the body's fluid and electrolyte levels change too rapidly, cells can struggle to correct the imbalance quickly enough. For example, consider a person exercising strenuously, losing water and electrolytes in the form of sweat, and drinking excessive amounts of water. The excess water dilutes the sodium in the blood, leading to ***hyponatremia***, or low blood sodium concentrations. Sodium levels within the cells are now more concentrated, leading water to enter the cells by osmosis. As a result, the cells swell with water and can burst if the imbalance is severe and prolonged.

In contrast, the opposite situation can occur in a person exercising strenuously for a long duration with inadequate fluid intake. This can lead to dehydration and ***hypernatremia***, or elevated blood sodium levels. The high concentration of sodium in the extracellular fluid causes water to leave cells by osmosis, making them shrink. 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.

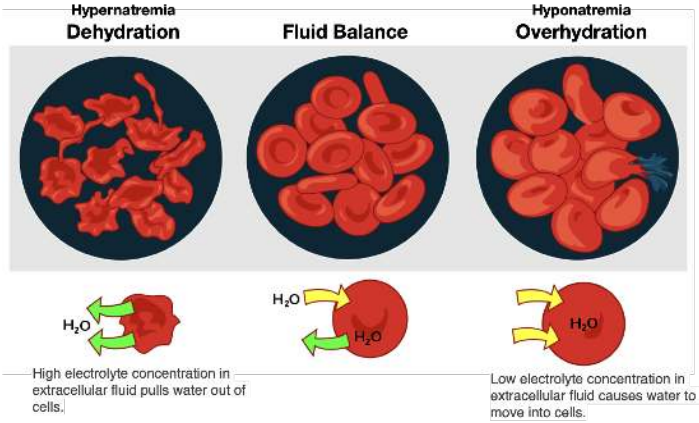


Figure 11.5.3: Effect of fluid imbalance on cells. With dehydration, the concentration of electrolytes becomes greater outside of cells, leading to water leaving cells and making them shrink. In fluid balance, electrolyte concentrations are in balance inside and outside of cells, so water is in balance 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. "Fluid Balance Effects on Cells" by Tamberly Powell is licensed under CC BY 4.0; edited from "Osmotic pressure on blood cells diagram" by LadyofHats is in the Public Domain.

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.

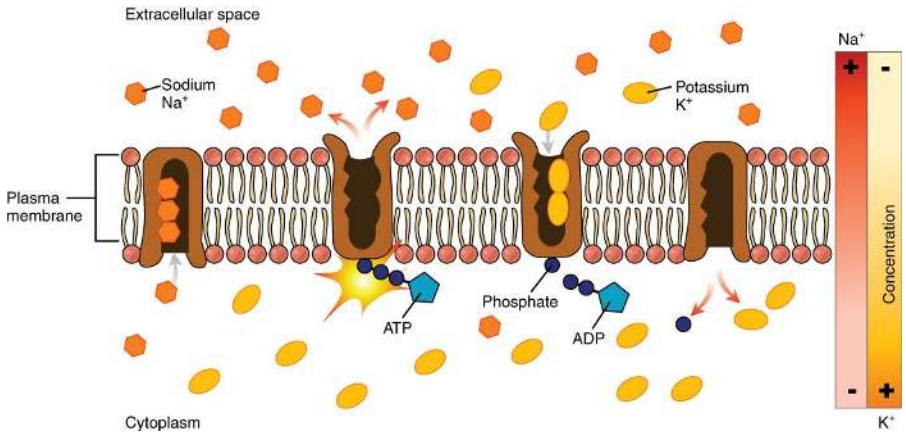


Figure 11.5.4: The sodium-potassium pump is found in many cell (plasma) membranes. Powered by ATP, the pump moves sodium and potassium ions in opposite directions, each against its concentration gradient. In a single cycle of the pump, three sodium ions are extruded from and two potassium ions are imported into the cell. "Sodium-Potassium Pump" by 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



Video 11.5.1: "Sodium Potassium Pump," by McGraw Hill Animations, YouTube (June 4, 2017), 2:02 minutes.

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.

References

Attributions

- Alice Callahan, Heather Leonard, & Tamberly Powell, Instructors (Nutrition) at Lane Community College, Sourced from OpenOregon

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11.6: 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.

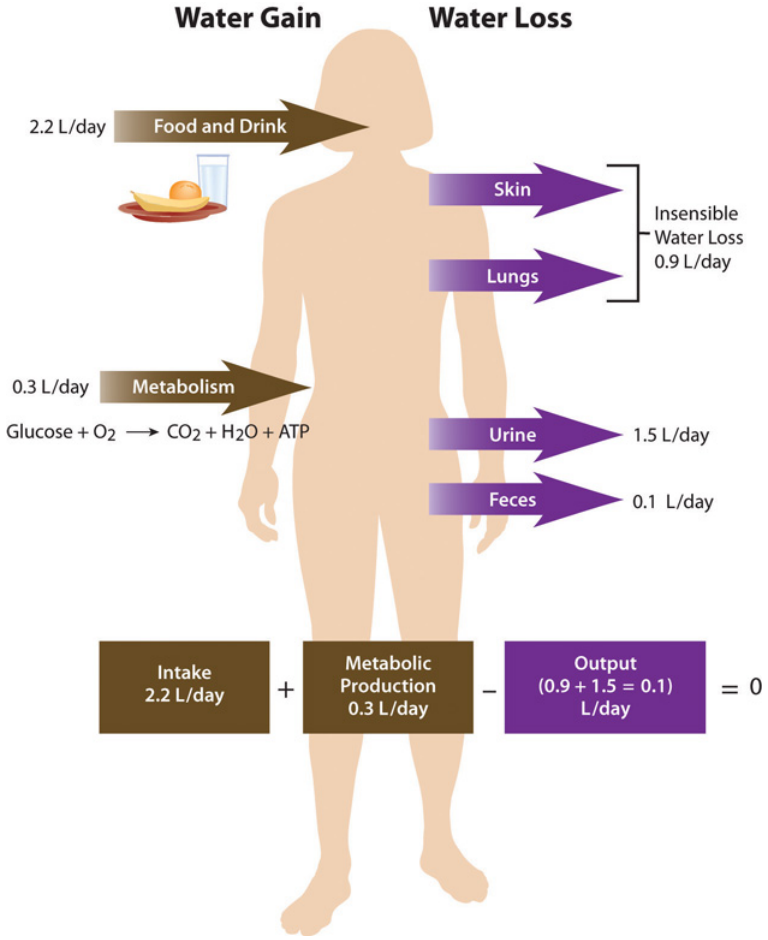


Figure 11.6.1: Daily Fluid Loss and Gain. CO2 + H20 + ATP); sources of water loss: Skin and lungs (insensible water loss 0.9 L/day), Urine 1.5 L/day, Feces 0.1 L/day. TOTAL intake 2.2 L/day + Metabolic Production 0.3 L/day – Output (0.9+1.5=0.1) L/day = 0 " class="wp-image-141 size-full" width="629″ 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 11.6.1 for the range of water contents for selected food items. Beverages includes water, tea, coffee, sodas, and juices.

Table 11.6.1: Water Content in Foods

Percentage	Food Item
90–99	Nonfat milk, cantaloupe, strawberries, watermelon, lettuce, cabbage, celery, spinach, squash
80–89	Fruit juice, yogurt, apples, grapes, oranges, carrots, broccoli, pears, pineapple
70–79	Bananas, avocados, cottage cheese, ricotta cheese, baked potato, shrimp
60–69	Pasta, legumes, salmon, chicken breast
50–59	Ground beef, hot dogs, steak, feta cheese
40–49	Pizza
30–39	Cheddar cheese, bagels, bread
20–29	Pepperoni, cake, biscuits
10–19	Butter, margarine, raisins
1–9	Walnuts, dry-roasted peanuts, crackers, cereals, pretzels, peanut butter
0	Oils, sugars

Source: 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.

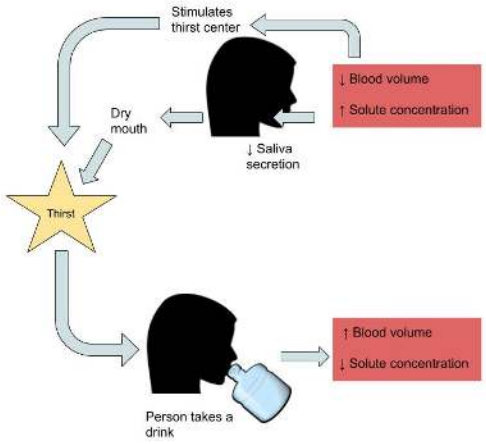


Figure 11.6.2: Regulating Water Intake. Image by Allison Calabrese / CC BY 4.0

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.

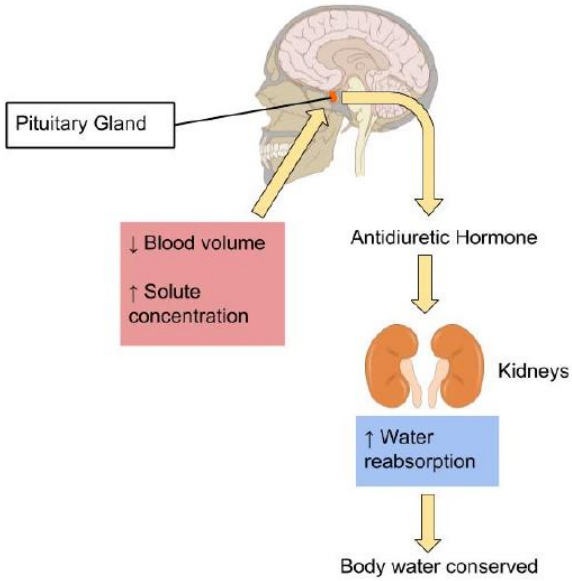


Figure 11.6.3: Regulating Water Output. Image by Allison Calabrese / CC BY 4.0

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.



Video 11.6.1: "What Would Happen if You Didn't Drink Water" by Mia Nacamulli, TED Ed, 4:51 minutes.

Resources

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11.7: 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 11.7.1: 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 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.

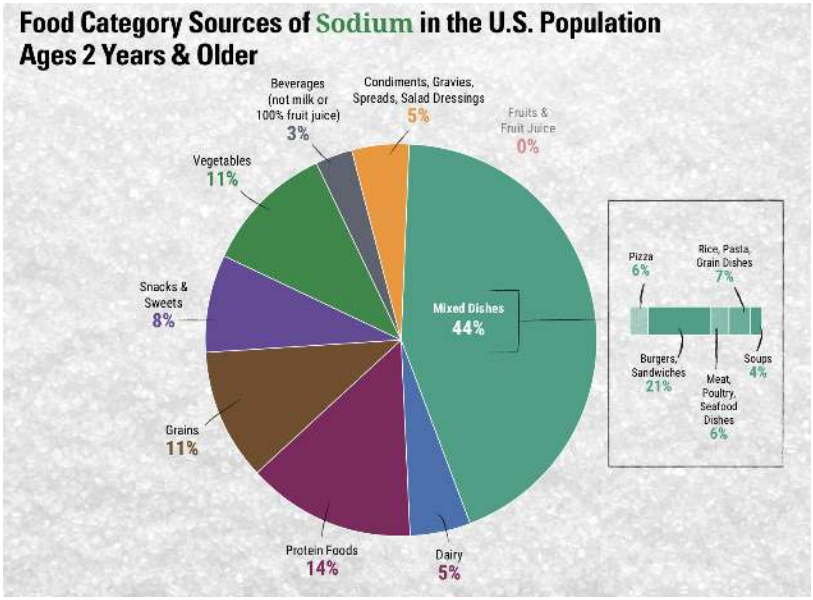


Figure 11.7.1: “Food Category Sources of Sodium in the U.S. Population Ages 2 Years & Older” from Dietary Guidelines for Americans, Figures 2-14 is in the public domain

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.

Table 11.7.2: 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

Food Group	Serving Size	Sodium (mg)
Chicken	(½ breast)	69
Chicken fast food dinner		2243
Chicken noodle soup	1 c.	1107
Dill pickle	1	928
Soy sauce	1 Tbsp.	1029
Canned corn	1 c.	384
Baked beans, canned	1 c.	856
Hot dog	1	639
Burger, fast-food	1	990
Steak	3 oz.	55
Canned tuna	3 oz.	384
Fresh tuna	3 oz.	50
Dry-roasted peanuts	1 c.	986
American cheese	1 oz.	406
Tap water	8 oz.	12

Sodium on the Nutrition Facts Panel



(For educational purposes only. These labels do not meet the labeling requirements described in 21 CFR 101.9.)

Figure 11.7.2: Nutrition Facts Label. Sodium level in milligrams is a required listing on a Nutrition Facts label. "Nutrition Facts Label Image" from the FDA is in the Public Domain.

The Nutrition Facts panel displays the amount of sodium (in milligrams) per serving of the food in question (Figure 11.7.2). If a food contains 20% or more of the Daily Value for sodium, it is considered a high-sodium food. 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 11.7.3).

Table 11.7.3: 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 11.7.4 displays the sodium and potassium amounts in some salt substitutes.

Table 11.7.4: 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

Product	Serving Size	Sodium (mg)	Potassium (mg)
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 11.7.5 for an AHA list of alternative food seasonings.

Table 11.7.5 Salt Alternatives

Seasoning	Foods
Allspice	Lean ground meats, stews, tomatoes, peaches, applesauce, cranberry sauce, gravies, lean meat
Almond extract	Puddings, fruits
Caraway seeds	Lean meats, stews, soups, salads, breads, cabbage, asparagus, noodles
Chives	Salads, sauces, soups, lean-meat dishes, vegetables
Cider vinegar	Salads, vegetables, sauces
Cinnamon	Fruits, breads, pie crusts
Curry powder	Lean meats (especially lamb), veal, chicken, fish, tomatoes, tomato soup, mayonnaise,
Dill	fish sauces, soups, tomatoes, cabbages, carrots, cauliflower, green beans, cucumbers, potatoes, salads, macaroni, lamb
Garlic (not garlic salt)	Lean meats, fish, soups, salads, vegetables, tomatoes, potatoes
Ginger	Chicken, fruits
Lemon juice	Lean meats, fish, poultry, salads, vegetables
Mace	Hot breads, apples, fruit salads, carrots, cauliflower, squash, potatoes, veal, lamb
Mustard (dry)	lean ground meats, lean meats, chicken, fish, salads, asparagus, broccoli, Brussels sprouts, cabbage, mayonnaise, sauces
Nutmeg	Fruits, pie crust, lemonade, potatoes, chicken, fish, lean meatloaf, toast, veal, pudding
Onion powder	Lean meats, stews, vegetables, salads, soups
Paprika	Lean meats, fish, soups, salads, sauces, vegetables
Parsley	Lean meats, fish, soups, salads, sauces, vegetables
Peppermint extract	Puddings, fruits
Pimiento	Salads, vegetables, casserole dishes

Seasoning	Foods
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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11.8: 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 11.8.1.

Table 11.8.1: 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
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.

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11.9: 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 IOM based their AIs for potassium on the levels associated with a decrease in blood pressure, a reduction in salt sensitivity, and a minimal risk of kidney stones. For adult male and females above the age of nineteen, the adequate intake for potassium is 4,700 grams per day. The AIs for other age groups are listed in Table 11.9.1.

Table 11.9.1: Adequate Intakes for Potassium

Age Group	mg/day
Infants (0–6 months)	400
Infants (6–12 months)	700
Children (1–3 years)	3,000
Children (4–8 years)	3,800
Children (9–13 years)	4,500
Adolescents (14–18 years)	4,700
Adults (> 19 years)	4,700

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 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] 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.

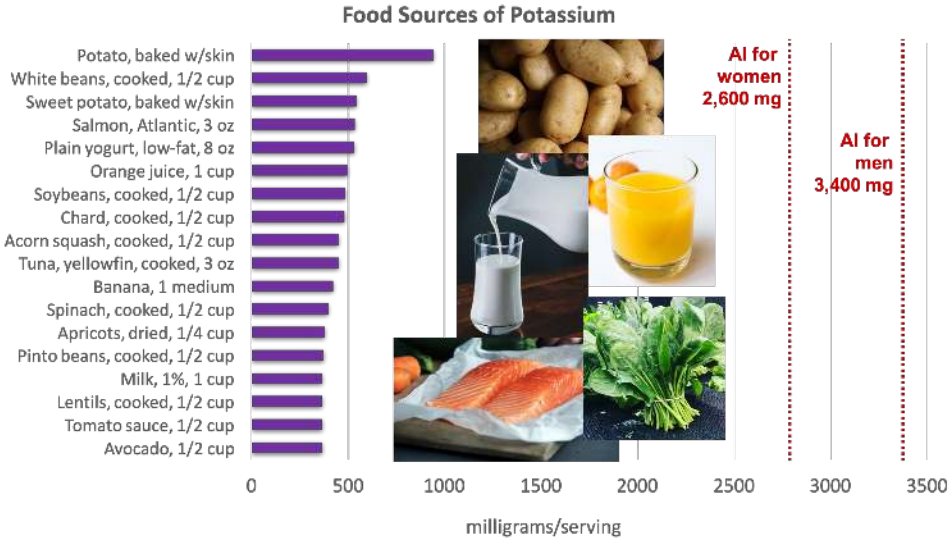


Figure 11.9.1: Dietary sources of potassium. Source: *Dietary Guidelines for Americans, 2015-2020*

Figure 8.11. Dietary sources of potassium. Source: *Dietary Guidelines for Americans, 2015-2020*

The 2020-2025 Dietary Guidelines for Americans identifies potassium as a "dietary component of public health concern," because dietary surveys consistently show that people in the United States consume less potassium than is recommended.[6] 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.[7] 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]

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11.10: 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 11.10.1: 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.

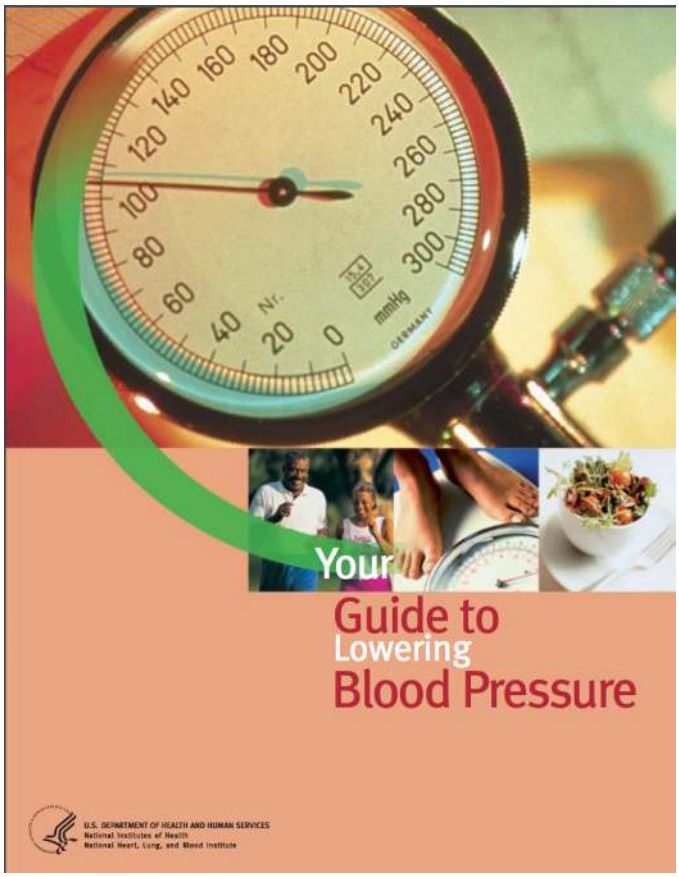


Figure 11.10.2: “Your Guide to Lowering Blood Pressure”. US Department of Health Services

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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11.11: Exercises - Water and Electrolytes

Exercises

Sodium Matching- Move the Claims to Match their Meaning

Claim	Meaning
Low Salt	Sodium is reduce
Salt Free	No salt added dur processing
Low in Sodium	50% less sodium added to similar f
Very Low Salt	Contains less thar serving
No Salt Added or Unsalted	Contains less thar serving
Lightly Salted	Contains less thar per serving

Check

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Drag the words into the correct boxes

Most sodium in the typical American diet comes from _____. Manufacturers add _____ to foods to _____ texture and flavor, and also as a _____.

Potassium plays an important role in _____. Potassium balances the effects of sodium on blood pressure because the _____ potassium you eat, the more sodium you _____ through urine.

_____ also involve both sodium and potassium. Similarly, in _____ potassium is involved in restoring the normal membrane potential and ending the _____

Nerve impulses
potassium
muscle cells
tomatoes
muscle contraction
more
salt
processed and prepared foods
preservative
lose
managing blood pressure
improve

Drag the words into the correct boxes

Electrolytes are substances that, when dissolved in water, dissociate into charged _____. Positively charged electrolytes are called _____ and negatively charged electrolytes are called _____.

cations
anions
ions

Check

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What is dehydration?

- ○ Dehydration occurs when you go more than one hour without drinking water.
- ○ Dehydration refers to water loss from the body without adequate replacement.
- ○ Dehydration is the state of too much water in the kidneys.

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11.12: Research Highlight

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... In the following publication... 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

APA citation

Further evaluation

To evaluate this publication further, it might help to...

References

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CHAPTER OVERVIEW

12: Nutrients Important as Antioxidants



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12.1: Introduction to Antioxidants
12.2: Generation of Free Radicals in the Body
12.3: Vitamin E
12.4: Vitamin C
12.5: Vitamin A and Beta-carotene
12.6: Selenium and Other Antioxidant Minerals
12.7: Phytochemicals
12.8: The Whole Nutrient Package versus Disease
12.9: Exercises - Antioxidants
12.10: Research Highlight - Cancer
12.11: EDIT Vitamins As Antioxidants - An Introduction

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12.1: Introduction to Antioxidants

Learning Objectives

- List several nutrients that serve as antioxidants.

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 supplements can actually cause harm. While scientists have found evidence supporting the consumption of antioxidant-rich foods as a method of reducing the risk of chronic disease, there is no “miracle cure”; no pill or supplement alone can provide the same benefits as a healthy diet.** Remember, it is the combination of antioxidants and other nutrients in healthy foods that is beneficial. In this section, we will review how particular antioxidants function in the body, learn how they work together to protect the body against free radicals, and explore the best nutrient-rich dietary sources of antioxidants. One dietary source of antioxidants is vitamins. In our discussion of antioxidant vitamins, we will focus on vitamins E, C, and A.



Figure 12.1.1: Photo by Dan-Cristian Pădureț / Unsplash License

Antioxidant Chemicals Obtained from the Diet

There are many different antioxidants in food, including selenium, which is one of the major antioxidants. However, the antioxidants you may be the most familiar with are vitamins. The “big three” vitamin antioxidants are vitamins E, A, and C, although it may be that they are called the “big three” only because they are the most studied.

Table 12.1.1: Some Antioxidants Obtained from Diet and Their Related Functions

Antioxidant	Antioxidant Source	Antioxidant Function
Vitamin A	Karat banana, beef liver, chicken liver	Protects cellular membranes, prevents glutathione depletion, maintains free radical detoxifying enzyme systems, reduces inflammation
Vitamin E	Sunflower seeds, almonds, sunflower oil	Protects cellular membranes, prevents glutathione depletion
Vitamin C	Oranges, grapefruit	Protects DNA, RNA, proteins, and lipids, aids in regenerating vitamin E
Vitamin D	Swordfish, salmon, tuna fish canned in water and drained	Regulates blood calcium levels in concert with parathyroid hormone
Carotenoids	Pumpkin, carrots	Free radical scavenger

What Are Antioxidants, and Why Do We Need Them?

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.

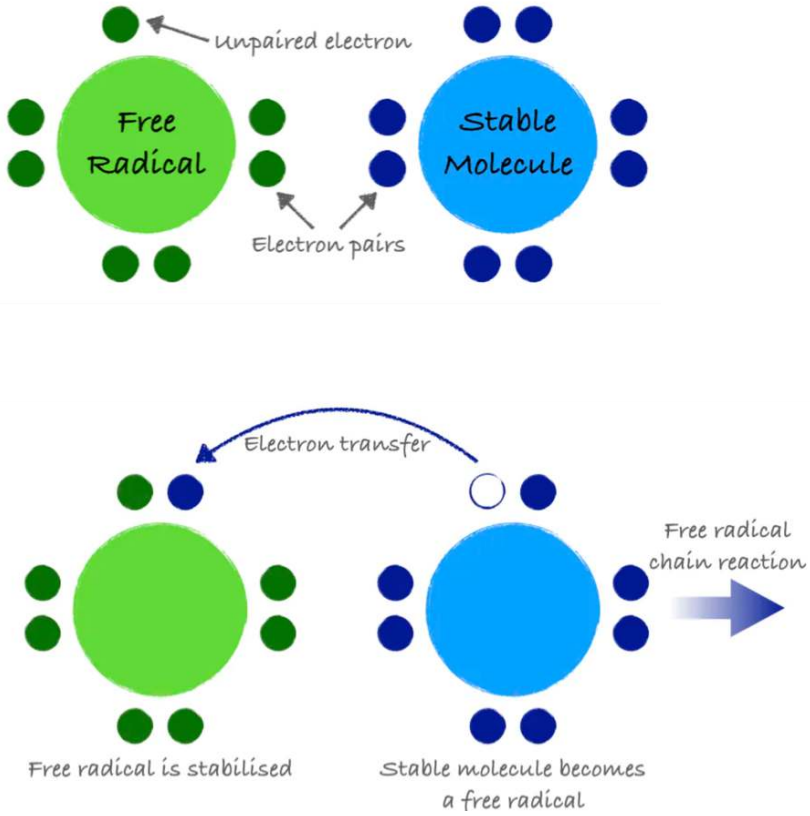


Figure 8.12. A free radical is a molecule with an unpaired electron. It can steal electrons from a stable molecule, creating a new free radical and initiating a chain reaction.

***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.

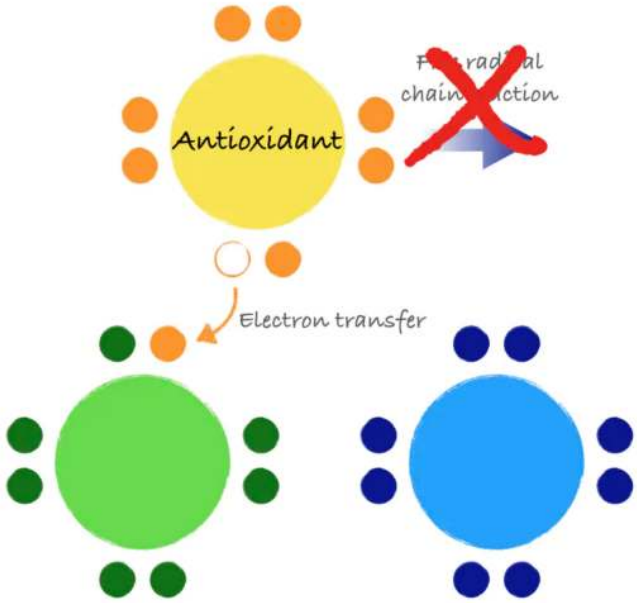


Figure 8.13. Antioxidants stabilize free radicals by donating electrons, preventing the chain reaction that can create more free radicals.

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.

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]

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12.2: Generation of Free Radicals in the Body

Learning Objectives

- Describe how free radicals are generated in the body.
- Explain oxidative stress and what diseases it is associated with.

In mainstream advertising you may have heard that antioxidants can extend your life by preventing disease and slowing the aging process. But what are antioxidants? And how do they work in the body? Is there any truth to the marketers' claims? Are there better sources than supplements for antioxidants? After reading this chapter you will be able to answer these questions, and your new knowledge will assist you in making dietary decisions to optimize your health.

Keep in mind as you read there is no scientific evidence that antioxidants *singularly* provide bodily benefits, but there is evidence that certain benefits are achieved by ingesting antioxidants as part of a balanced, healthy, nutrient-rich diet. This is to say antioxidants may go a long way toward preventing damage, but other nutrients are necessary to repair damage and sustain health. No one chemical acts alone!

The Atom

Before we can talk about the nutritional value of antioxidants we must review a few chemistry basics, starting with the atom. Cells are the basic building blocks of life, but atoms are the basic building blocks of all matter, living and nonliving.

The structural elements of an atom are protons (positively charged), neutrons (no charge), and electrons (negatively charged). Protons and neutrons are contained in the dense nucleus of the atom; the nucleus thus has a positive charge. Because opposites attract, electrons are attracted to this nucleus and move around it in the electron cloud.

Electrons contain energy, and this energy is stored within the charge and movement of electrons and the bonds 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 potential energy. By bonding, electrons find pairs and chemicals become part of a molecule.

Bond formation and bond breaking are chemical reactions that involve the movement of electrons between atoms. These chemical reactions occur continuously in the body and many of them will be discussed in more detail later.

Previous, we reviewed how glucose breaks down into water and carbon dioxide as part of cellular respiration. The energy released by breaking those bonds is used to form molecules of adenosine triphosphate (ATP). Recall how during this process electrons are extracted from glucose in a stepwise manner and transferred to other molecules. Occasionally electrons "escape" and, instead of completing the cellular respiration cycle, are transferred to an oxygen molecule. Oxygen (a molecule with two atoms) with one unpaired electron is known as superoxide (Figure 12.2.1).

Atoms and molecules such as superoxide that have unpaired electrons are called free radicals; those containing oxygen are more specifically referred to as reactive oxygen species. The unpaired electron in free radicals destabilizes them, making them highly reactive. Other reactive oxygen species include hydrogen peroxide and the hydroxyl radical.



Figure 12.2.1: Superoxide: A molecule with one unpaired electron, which makes it a free radical. Source: Wikipedia. "Superoxide." Last modified November 2, 2012. (CC-BY-SA 3.0; DoSiDo).

The reactivity of free radicals is what poses a threat to macromolecules such as DNA, RNA, proteins, and fatty acids. Free radicals can cause chain reactions that ultimately damage cells. For example, a superoxide molecule may react with a fatty acid and steal one of its electrons. The fatty acid then becomes a free radical that can react with another fatty acid nearby. As this chain reaction continues, the permeability and fluidity of cell membranes changes, proteins in cell membranes experience decreased activity, and receptor proteins undergo changes in structure that either alter or stop their function. If receptor proteins designed to react to insulin levels undergo a structural change it can negatively effect glucose uptake.

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

The Body's Defense

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

Free Radical Detoxifying Enzymes

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

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

Antioxidant Chemicals

Antioxidants are broadly classified as either hydrophilic (water soluble) or hydrophobic (lipid soluble) chemicals, and this classification determines where they act in the body. Hydrophilic antioxidants act in the cytosol of cells or in extracellular fluids such as blood; hydrophobic antioxidants are largely responsible for protecting cell membranes from free radical damage.

The body can synthesize some antioxidants, but others must be obtained from the diet.

Antioxidant Chemicals the Body Synthesizes

There are two antioxidant chemicals that the body synthesizes. They are:

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

Antioxidant Chemicals Obtained from the Diet

There are many different antioxidants in food, including selenium, which is one of the major antioxidants. However, the antioxidants you may be the most familiar with are vitamins. The "big three" vitamin antioxidants are vitamins E, A, and C, although it may be that they are called the "big three" only because they are the most studied.

Table 12.2.1: Some Antioxidants Obtained from Diet and Their Related Functions

Antioxidant	Functions Attributed to Antioxidant Capacity
Vitamin A	Protects cellular membranes, prevents glutathione depletion, maintains free radical detoxifying enzyme systems, reduces inflammation
Vitamin E	Protects cellular membranes, prevents glutathione depletion
Vitamin C	Protects DNA, RNA, proteins, and lipids, aids in regenerating vitamin E
Carotenoids	Free radical scavengers

Antioxidant	Functions Attributed to Antioxidant Capacity
Lipoic acid	Free radical scavenger, aids in regeneration of vitamins C and E
Phenolic acids	Free radical scavengers, protect cellular membranes
Selenium	Cofactor of free radical detoxifying enzymes, maintains glutathione levels, aids in regeneration of vitamins C and E

The Body's Offense

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

Scientific studies also suggest hydrogen peroxide acts as a signaling molecule that calls immune cells to injury sites, meaning free radicals may aid with tissue repair when you get cut.

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

By acting as signaling molecules, free radicals are involved in the control of their own synthesis, stress responses, regulation of cell growth and death, and metabolism.

Sources of Free Radicals in the Environment

The body creates free radicals through the normal processes of metabolism. When the amount of free radicals exceeds the body's ability to eliminate or neutralize them, an oxidative imbalance results.

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



Video 12.2.1: Free Radical Formation.

Oxidative Stress

Oxidative stress refers to an imbalance in any cell, tissue, or organ between the amount of free radicals and the capablilities of the detoxifying and repair systems. Sustained oxidative damage results only under conditions of oxidative stress—when the detoxifying and repair systems are insufficient. 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, atherosclerosis

(hardening of arteries), arthritis, diabetes, kidney disease, Alzheimer's disease, Parkinson's disease, schizophrenia, bipolar disorder, emphysema, and cataracts.

Aging is a process that is genetically determined but modulated by factors in the environment. In the process of aging, tissue function declines. The idea that oxidative stress is the primary contributor to age-related tissue decline has been around for decades, and it is true that tissues accumulate free radical-induced damage as we age. Recent scientific evidence slightly modifies this theory by suggesting oxidative stress is not the initial trigger for age-related decline of tissues; it is suggested that the true culprit is progressive dysfunction of metabolic processes, which leads to increases in free radical production, thus influencing the stress response of tissues as they age.

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

Key Takeaways

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

Discussion Starter

1. What are some ways you can prevent exposure to environmental factors that increase free radical production in your body?

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12.3: Vitamin E

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

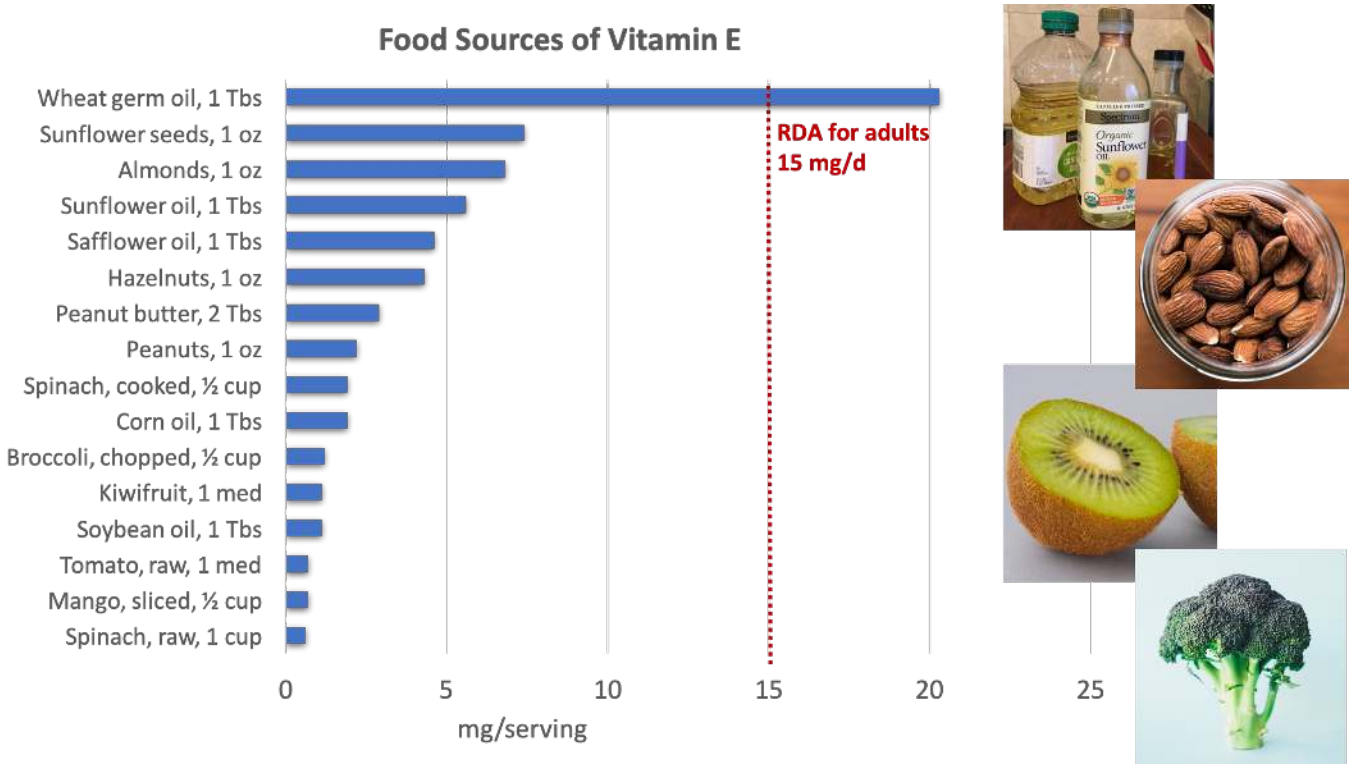


Figure *8.14. Dietary sources of vitamin E. Source: NIH Office of Dietary Supplements*

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

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

Vitamin E Functions and Health Benefits

Vitamin E is actually eight chemically similar substances, of which alpha-tocopherol appears to be the most potent antioxidant. Alpha-tocopherol and vitamin E's other constituents are fat-soluble and primarily responsible for protecting cell membranes against lipid destruction caused by free radicals.

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, can change the functions of proteins in cells, plays a role in the operations of the immune system, enhances the dilation of blood vessels, and inhibits blood clot formation. Despite vitamin E's numerous beneficial functions when taken in recommended amounts, large studies do not support the idea that taking higher doses of this vitamin will increase its power to prevent or reduce disease risk.Goodman, M., Bostlick RM, Kucuk O, Jones DP. 2011. Clinical trials of antioxidants as cancer prevention agents: past, present, and future. Free Radic Biol Med. 51(5): 1068–84.' McGinley C, Shafat A. Donnelly AE. 2009. Does antioxidant vitamin supplementation protect against muscle damage. Sports Med. 39(12): 1011–32.

Cardiovascular Disease

Recall that low-density lipoproteins (LDLs) transport cholesterol and other lipids from the liver to the rest of the body. LDLs are often referred to as "bad cholesterol," as an elevation in their levels in the blood is a risk factor for cardiovascular disease. Oxidation of the lipids and proteins in LDLs causes them to stick to the walls of arteries and this contributes to the development of fatty streaks and, eventually, plaque, which hardens the arteries. Hardening of the arteries, called atherosclerosis can lead to a heart attack.

Vitamin E reduces the oxidation of LDLs, and it was therefore hypothesized that vitamin E supplements would protect against atherosclerosis. However, large clinical trials have not consistently found evidence to support this hypothesis. In fact, in the "Women's Angiographic Vitamin and Estrogen Study," postmenopausal women who took 400 international units (264 milligrams) of vitamin E and 500 milligrams of vitamin C twice per day had higher death rates from all causes.Waters, D.D. et al. "Effects of Hormone Replacement Therapy and Antioxidant Vitamin Supplements on Coronary Atherosclerosis in Postmenopausal Women: A Randomized Controlled Trial." *JAMA* 288, no. 19 (2002): 2432–40. doi: 10.1001/jama.288.19.2432

Other studies have not confirmed the association between increased vitamin E intake from supplements and increased mortality. There is more consistent evidence from observational studies that a higher intake of vitamin E from foods is linked to a decreased risk of dying from a heart attack.

Cancer

The large clinical trials that evaluated whether there was a link between vitamin E and cardiovascular disease risk also looked at cancer risk. These trials, called the HOPE-TOO Trial and Women's Health Study, did not find that vitamin E at doses of 400 international units (264 milligrams) per day or 600 international units (396 milligrams) every other day reduced the risk of developing any form of cancer.HOPE and HOPE-TOO Trial Investigators. "Effects of Long-Term Vitamin E Supplementation on Cardiovascular Events and Cancer." *JAMA* 293 (2005):1338–47. jama.ama-assn.org/content/293/11/1338.long.' Lee, I-M., et al. "Vitamin E in the Primary Prevention of Cardiovascular Disease and Cancer: The Women's Health Study." *JAMA* 294 (2005): 56–65. jama.ama-assn.org/content/294/1/56.long.

Eye Conditions

Oxidative stress plays a role in age-related loss of vision, called macular degeneration. Age-related macular degeneration (AMD) primarily occurs in people over age fifty and is the progressive loss of central vision resulting from damage to the center of the retina, referred to as the macula. There are two forms of AMD, dry and wet, with wet being the more severe form.

In the dry form, deposits form in the macula; the deposits may or may not directly impair vision, at least in the early stages of the disease. In the wet form, abnormal blood vessel growth in the macula causes vision loss. Clinical trials evaluating the effects of vitamin E supplements on AMD and cataracts (clouding of the lens of an eye) did not consistently observe a decreased risk for either. However, scientists do believe vitamin E in combination with other antioxidants such as zinc and copper may slow the progression of macular degeneration in people with early-stage disease.

Dementia

The brain's high glucose consumption makes it more vulnerable than other organs to oxidative stress. Oxidative stress has been implicated as a major contributing factor to dementia and Alzheimer's disease. Some studies suggest vitamin E supplements delay the progression of Alzheimer's disease and cognitive decline, but again, not all of the studies confirm the relationship. A recent study with over five thousand participants published in the July 2010 issue of the *Archives of Neurology* demonstrated that people with the highest intakes of dietary vitamin E were 25 percent less likely to develop dementia than those with the lowest intakes of vitamin E.Devore, E. E. et al. "Dietary Antioxidants and Long-Term Risk of Dementia." *Arch Neurol* 67, no.7 (2010): 819–25. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2923546/?tool=pubmed. More studies are needed to better assess the dose and dietary requirements of vitamin E and, for that matter, whether other antioxidants lower the risk of dementia, a disease that not only devestates the mind, but also puts a substantial burden on loved ones, caretakers, and society in general.

Dietary Reference Intakes for Vitamin E

The Recommended Dietary Allowances (RDAs) and Tolerable Upper Intake Levels (ULs) for different age groups for vitamin E are given in Table 12.3.1. The RDAs are based on scientific evidence that these levels of vitamin E in the diet prevent conditions associated with vitamin E deficiency, which are rare (signs and symptoms of such conditions are not always evident) but are primarily the result of nerve degeneration. People with malabsorption disorders, such as Crohn's disease or cystic fibrosis, and babies born prematurely, are at higher risk for vitamin E deficiency.

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

Table 12.3.1: *Dietary Reference Intakes for Vitamin E*

Age Group	RDA Males and Females mg/day	UL
Infants (0–6 months)	4*	–
Infants (7–12 months)	5*	–
Children (1–3 years)	6	200
Children (4–8 years)	7	300
Children (9–13 years)	11	600
Adolescents (14–18 years)	15	800
Adults (> 19 years)	15	1,000
*denotes Adequate Intake		

Source: National Institutes of Health, Office of Dietary Supplements. "Dietary Supplement Fact Sheet: Vitamin E." Last modified October 11, 2011. http://ods.od.nih.gov/factsheets/VitaminE-QuickFacts/.

Vitamin E supplements often contain more than 400 international units, which is almost twenty times the RDA. The UL for vitamin E is set at 1,500 international units for adults. There is some evidence that taking vitamin E supplements at high doses has negative effects on health. As mentioned, vitamin E inhibits blood clotting and a few clinical trials have found that people taking vitamin E supplements have an increased risk of stroke. In contrast to vitamin E from supplements, there is no evidence that consuming foods containing vitamin E compromises health.

Dietary Sources of Vitamin E

Vitamin E is found in many foods, especially those higher in fat, such as nuts and oils. Some spices, such as paprika and red chili pepper, and herbs, such as oregano, basil, cumin, and thyme, also contain vitamin E. (Keep in mind spices and herbs are commonly used in small amounts in cooking and therefore are a lesser source of dietary vitamin E.) See Table 12.3.2 for a list of foods and their vitamin E contents.

> *To increase your dietary intake of vitamin E from plant-based foods try a spinach salad with tomatoes and sunflower seeds, and add a dressing made with sunflower oil, oregano, and basil.*

Table 12.3.2: Vitamin E Content of Various Foods

Food	Vitamin E (mg)	Percent Daily Value
Wheat-germ oil (1 Tbsp.)	20.3	100
Sunflower seeds (1 oz.)	7.4	37
Almonds (1 oz.)	6.8	34
Sunflower oil (1 Tbsp.)	5.6	28
Safflower oil (1 Tbsp.)	4.6	23
Hazelnuts (1 oz.)	4.3	22
Peanut butter (2 Tbsp.)	2.9	15
Peanuts (1 oz.)	2.2	11
Corn oil (1 Tbsp.)	1.9	10
Kiwi (1 medium)	1.1	6
Tomato (1 medium)	0.7	4
Spinach (1 c. raw)	0.6	3

Source: National Institutes of Health, Office of Dietary Supplements. “Dietary Supplement Fact Sheet: Vitamin E.” Last reviewed October 11, 2011. http://ods.od.nih.gov/factsheets/VitaminE-HealthProfessional/.

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12.4: Vitamin C

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.

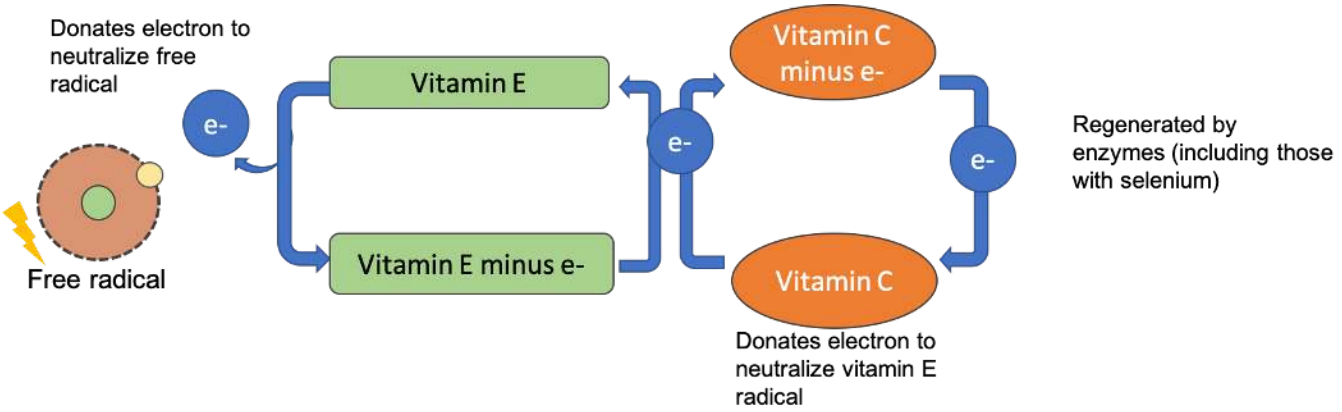


Figure 8.15. After vitamin E donates an electron to neutralize a free radical, it can be regenerated by an electron from vitamin C. Vitamin C is then regenerated by antioxidant enzymes.

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.

Food Sources of Vitamin C

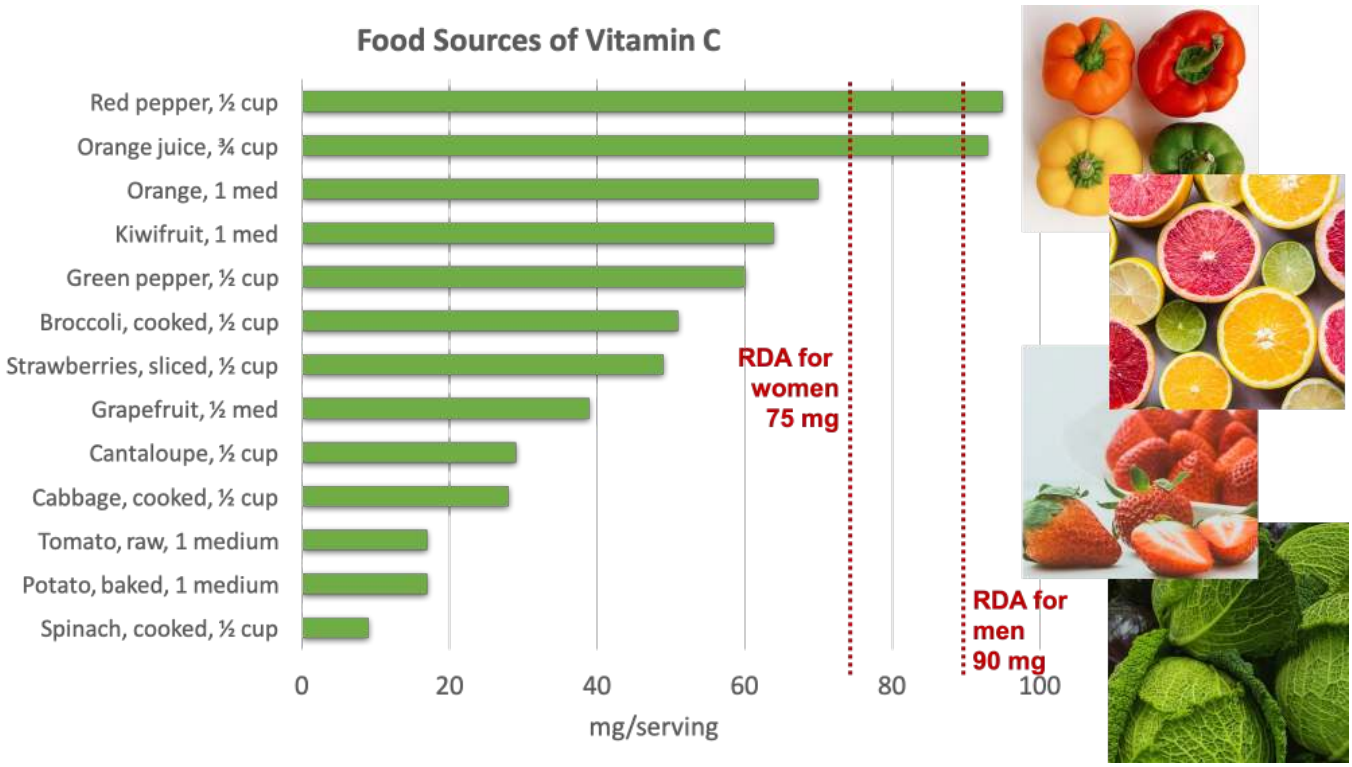


Figure 8.16. Dietary sources of vitamin C. Source: NIH *Office of Dietary Supplements*

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.

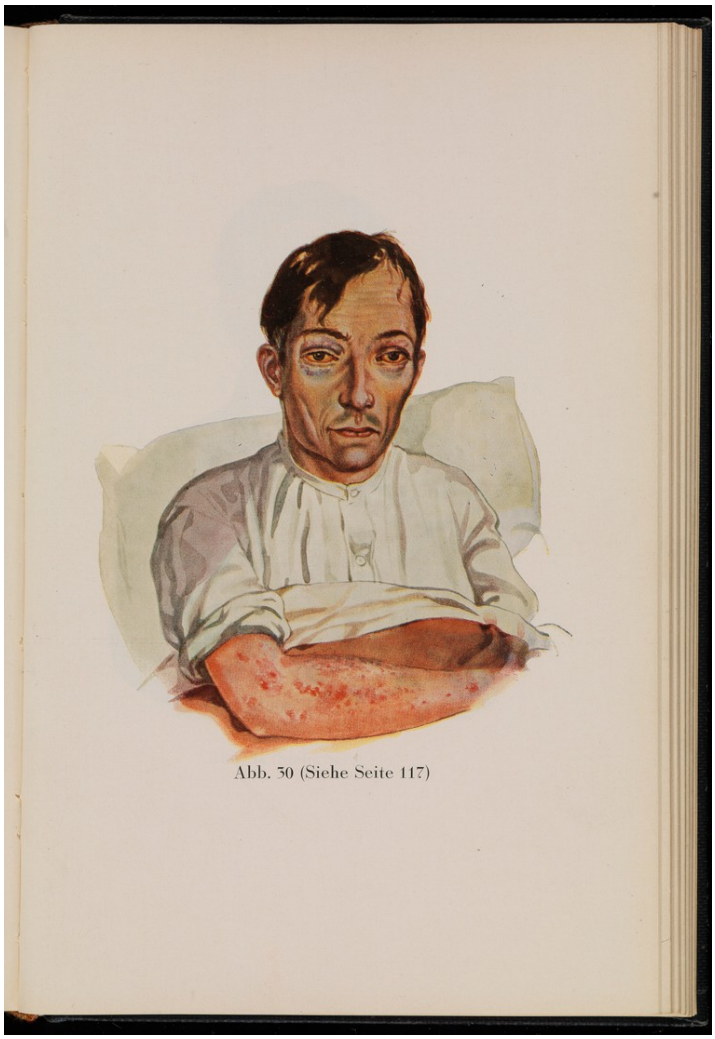


Figure 8.17. This drawing of a sailor with scurvy, from the 1929 edition of "Kranken-Physiognomik" by von K. H. Baumgärtner, shows common effects of the disease, including sunken eyes and skin lesions.

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.

Can Vitamin C Supplements Prevent the Common Cold?

Many people believe that taking a vitamin C supplement can prevent the common cold or decrease its symptoms. This idea was popularized by Linus Pauling in the 1970s, and it's continuously promoted today in the form of over-the-counter supplements such

as Emergen-C and Airborne. These typically contain doses in the range of 1000 mg of vitamin C, far higher than normal levels of vitamin C in the diet and enough to reach the UL of 2000 mg if a person takes two doses per day.



Vitamin C Functions and Health Benefits

Vitamin C, also commonly called ascorbic acid, is a water-soluble micronutrient essential in the diet for humans, although most other mammals can readily synthesize it. Vitamin C's ability to easily donate electrons makes it a highly effective antioxidant. It is effective in scavenging reactive oxygen species, reactive nitrogen species, and many other free radicals. It protects lipids both by disabling free radicals and by aiding in the regeneration of vitamin E.

In addition to its role as an antioxidant, vitamin C is a required part of several enzymes involved in the synthesis of collagen, signaling molecules in the brain, some hormones, and amino acids. Vitamin C levels in the body are affected by the amount in the diet, which influences how much is absorbed and how much the kidney allows to be excreted, such that the higher the intake, the more vitamin C is excreted. Vitamin C is not stored in any significant amount in the body, but once it has reduced a free radical, it is very effectively regenerated and therefore it can exist in the body as a functioning antioxidant for many weeks.

Cardiovascular Disease

Vitamin C's ability to prevent disease has been debated for many years. Overall, higher dietary intakes of vitamin C (via food intake, not supplements), are linked to decreased disease risk. A review of multiple studies published in the April 2009 issue of the *Archives of Internal Medicine* concludes there is moderate scientific evidence supporting the idea that higher dietary vitamin C intakes are correlated with reduced cardiovascular disease risk, but there is insufficient evidence to conclude that taking vitamin C supplements influences cardiovascular disease risk.Mente, A., et al. "A Systematic Review of the Evidence Supporting a Causal Link between Dietary Factors and Coronary Heart Disease." *Arch Intern Med* 169, no.7 (2009): 659–69. archinte.ama-assn.org/cgi/content/full/169/7/659.

Vitamin C levels in the body have been shown to correlate well with fruit and vegetable intake, and higher plasma vitamin C levels are linked to reduced risk of some chronic diseases. In a study involving over twenty thousand participants, people with the highest levels of circulating vitamin C had a 42 percent decreased risk for having a stroke.Myint, P.K. et al. "Plasma Vitamin C Concentrations Predict Risk of Incident Stroke Over 10 Y[ears] in 20,649 Participants of the European Prospective Investigation into Cancer, Norfolk Prospective Population Study." *Am J Clin Nutr* 87, no.1 (2008): 64–69. http://www.ajcn.org/content/87/1/64.long.

Cancer

There is some evidence that a higher vitamin C intake is linked to a reduced risk of cancers of the mouth, throat, esophagus, stomach, colon, and lung, but not all studies confirm this is true. As with the studies on cardiovascular disease, the reduced risk of cancer is the result of eating foods rich in vitamin C, such as fruits and vegetables, not from taking vitamin C supplements. In these studies, the specific protective effects of vitamin C cannot be separated from the many other beneficial chemicals in fruits and vegetables.

Immunity

Vitamin C does have several roles in the immune system, and many people increase vitamin C intake either from diet or supplements when they have a cold. Many others take vitamin C supplements routinely to prevent colds. Contrary to this popular practice, however, there is no good evidence that vitamin C prevents a cold. A review of more than fifty years of studies published in 2004 in the *Cochrane Database of Systematic Reviews* concludes that taking vitamin C routinely does not prevent colds in most people, but it does slightly reduce cold severity and duration. Moreover, taking megadoses (up to 4 grams per day) at the onset of a cold provides no benefits.Douglas, R.M. et al. "Vitamin C for Preventing and Treating the Common Cold." *Cochrane Database of Systematic Reviews* 4 (2004): CD000980. http://www.ncbi.nlm.nih.gov/pubmed/15495002?dopt=Abstract.

Gout is a disease caused by elevated circulating levels of uric acid and is characterized by recurrent attacks of tender, hot, and painful joints. There is some evidence that a higher intake of vitamin C reduces the risk of gout.

Dietary Reference Intakes for Vitamin C

The classic condition associated with vitamin C deficiency is scurvy. The signs and symptoms of scurvy include skin disorders, bleeding gums, painful joints, weakness, depression, and increased susceptibility to infections. Scurvy is prevented by having an Adequate Intake of fruits and vegetables rich in vitamin C.

The RDAs and ULs for different age groups for vitamin C are listed in Table 12.4.4. They are considered adequate to prevent scurvy. Vitamin C's effectiveness as a free radical scavenger motivated the Institute of Medicine (IOM) to increase the RDA for smokers by 35 milligrams, as tobacco smoke is an environmental and behavioral contributor to free radicals in the body.

Table 12.4.4: Dietary Reference Intakes for Vitamin C

Age Group	RDA Males and Females mg/day	UL
Infants (0–6 months)	40*	–
Infants (7–12 months)	50*	–
Children (1–3 years)	15	400
Children (4–8 years)	25	650
Children (9–13 years)	45	1200
Adolescents (14–18 years)	75 (males), 65 (females)	1800
Adults (> 19 years)	90 (males), 75 (females)	2000
*denotes Adequate Intake		

Source: National Institutes of Health, Office of Dietary Supplements. "Dietary Supplement Fact Sheet: Vitamin C." Last reviewed June 24, 2011. http://ods.od.nih.gov/factsheets/VitaminC-QuickFacts/.

High doses of vitamin C have been reported to cause numerous problems, but the only consistently shown side effects are gastrointestinal upset and diarrhea. To prevent these discomforts the IOM has set a UL for adults at 2,000 milligrams per day (greater than twenty times the RDA).

At very high doses in combination with iron, vitamin C has sometimes been found to increase oxidative stress, reaffirming that getting your antioxidants from foods is better than getting them from supplements, as that helps regulate your intake levels. There is some evidence that taking vitamin C supplements at high doses increases the likelihood of developing kidney stones, however, this effect is most often observed in people that already have multiple risk factors for kidney stones.

Dietary Sources of Vitamin C

Citrus fruits are great sources of vitamin C and so are many vegetables. In fact, British sailors in the past were often referred to as "limeys" as they carried sacks of limes onto ships to prevent scurvy. Vitamin C is not found in significant amounts in animal-based foods.

Because vitamin C is water soluble, it leaches away from foods considerably during cooking, freezing, thawing, and canning. Up to 50 percent of vitamin C can be boiled away. Therefore, to maximize vitamin C intake from foods, you should eat fruits and vegetables raw or lightly steamed. For the vitamin C content of various foods, see Table 12.4.5.

Table 12.4.5: Vitamin C Content of Various Foods

Food	Serving	Vitamin C (mg)
Orange juice	6 oz.	62–93
Grapefruit juice	6 oz.	62–70
Orange	1 medium	70
Grapefruit	½ medium	38
Strawberries	1 c.	85
Tomato	1 medium	16
Sweet red pepper	½ c. raw	95
Broccoli	½ c. cooked	51
Asparagus	1 c. cooked	20
Romaine lettuce	2 c.	27
Kale	1 c. boiled	53
Cauliflower	1 c. boiled	55
Potato	1 medium, baked	17

Source: National Institutes of Health, Office of Dietary Supplements. “Dietary Supplement Fact Sheet: Vitamin C.” Last reviewed June 24, 2011. http://ods.od.nih.gov/factsheets/VitaminC-HealthProfessional/.

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12.5: Vitamin A and Beta-carotene

Vitamin A Functions and Health Benefits

Vitamin A is a generic term for a group of similar compounds called retinoids. Retinol is the form of vitamin A found in animal-derived foods, and it is converted in the body to the biologically active forms of vitamin A: retinal and retinoic acid (thus retinol is sometimes referred to as “preformed vitamin A”). About 10 percent of plant-derived carotenoids, including beta-carotene, can be converted in the body to retinoids and are another source of functional vitamin A. The retinoids are aptly named as their most notable function is in the retina of the eye where they aid in vision, particularly in seeing under low-light conditions. This is why night blindness is the most definitive sign of vitamin A deficiency.

Like vitamin E, vitamin A is fat-soluble and is packaged into chylomicrons in small intestine mucosal cells, and then transported to the liver. The liver stores and exports vitamin A as needed; it is released into the blood bound to a retinol-binding protein, which transports it to cells.

Vitamin A has several important functions in the body, including maintaining vision and a healthy immune system. Many of vitamin A’s functions in the body are similar to the functions of hormones (for example, vitamin A can interact with DNA, causing a change in protein function). Vitamin A assists in maintaining healthy skin and the linings and coverings of tissues; it also regulates growth and development. As an antioxidant, vitamin A protects cellular membranes, helps in maintaining glutathione levels, and influences the amount and activity of enzymes that detoxify free radicals.

Vision

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

Insufficient intake of dietary vitamin A over time can also cause complete vision loss. In fact, vitamin A deficiency is the number one cause of preventable blindness worldwide. Vitamin A not only supports the vision function of eyes but also maintains the coverings and linings of the eyes. Vitamin A deficiency can lead to the dysfunction of the linings and coverings of the eye, causing dryness of the eyes, a condition called xerophthalmia. This condition can progress, causing ulceration of the cornea and eventually blindness.

Immunity

The common occurrence of advanced xerophthalmia in children who died from infectious diseases led scientists to hypothesize that supplementing vitamin A in the diet for children with xerophthalmia might reduce disease-related mortality. In Asia in the late 1980s, targeted populations of children were administered vitamin A supplements, and the death rates from measles and diarrhea declined by up to 50 percent. Vitamin A supplementation in these deficient populations did not reduce the number of children who contracted these diseases, but it did decrease the severity of the diseases so that they were no longer fatal. Soon after the results of these studies were communicated to the rest of the world, the World Health Organization (WHO) and the United Nations Children’s Fund (UNICEF) commenced worldwide campaigns against vitamin A deficiency. UNICEF estimates that the distribution of over half a billion vitamin A capsules prevents 350,000 childhood deaths annually.Sommer, A. “Vitamin A Deficiency and Clinical Disease: An Historical Overview.” *J Nutr* 138 (2008):1835–39. http://jn.nutrition.org/content/138/10/1835.long.

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

Growth and Development

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

In the fetal stages of life, vitamin A is important for limb, heart, eye, and ear development and in both deficiency and excess, vitamin A causes birth defects. Furthermore, both males and females require vitamin A in the diet to effectively reproduce.

Cancer

Vitamin A's role in regulating cell growth and death, especially in tissues that line and cover organs, suggests it may be effective in treating certain cancers of the lung, neck, and liver. It has been shown in some observational studies that vitamin A-deficient populations have a higher risk for some cancers. However, vitamin A supplements have actually been found to increase the risk of lung cancer in people who are at high risk for the disease (i.e., smokers, exsmokers, workers exposed to asbestos). The Beta-Carotene and Retinol Efficacy Trial (CARET) involving over eighteen thousand participants who were at high risk for lung cancer found that people who took supplements containing very high doses of vitamin A (25,000 international units) and beta-carotene had a 28 percent higher incidence of lung cancer midway through the study, which was consequently stopped.Goodman, G.E. et al. "The Beta-Carotene and Retinol Efficacy Trial: Incidence of Lung Cancer and Cardiovascular Disease Mortality During 6-year Follow-up after Stopping Beta-Carotene and Retinol Supplements." *J Natl Cancer Inst* 96, no. 23 (2004): 1743–50. http://jnci.oxfordjournals.org/content/96/23/1743.long.

Vitamin A supplementation is a relatively common practice in treating some types of cancer patients and is thought to improve the effectiveness of some anticancer drugs, but many oncologists (physicians who treat cancer patients) do not recommend this practice as vitamin A may actually inhibit the actions of some anticancer drugs.

Vitamin A Toxicity

Vitamin A toxicity, or hypervitaminosis A, is rare. Typically it requires you to ingest ten times the RDA of preformed vitamin A in the form of supplements (it would be hard to consume such high levels from a regular diet) for a substantial amount of time, although some people may be more susceptible to vitamin A toxicity at lower doses. The signs and symptoms of vitamin A toxicity include dry, itchy skin, loss of appetite, swelling of the brain, and joint pain. In severe cases, vitamin A toxicity may cause liver damage and coma.

Vitamin A is essential during pregnancy, but doses above 3,000 micrograms per day (10,000 international units) have been linked to an increased incidence of birth defects. Pregnant women should check the amount of vitamin A contained in any prenatal or pregnancy multivitamin she is taking to assure the amount is below the UL.

Dietary Reference Intakes for Vitamin A

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

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

The RDA for vitamin A includes all sources of vitamin A. The amount of vitamin A obtained from carotenoids—the retinol activity equivalent (RAE)—can be calculated. For example, 12 micrograms of fruit- or vegetable-based beta-carotene will yield 1 microgram of retinol, as mentioned.

The RDA for vitamin A is considered sufficient to support growth and development, reproduction, vision, and immune system function while maintaining adequate stores (good for four months) in the liver.

Table 12.5.6: Dietary Reference Intakes for Vitamin A

Age Group	RDA Males and Females mcg/day	UL
Infants (0–6 months)	400*	600
Infants (7–12 months)	500*	600
Children (1–3 years)	300	600
Children (4–8 years)	400	900
*denotes Adequate Intake		

Age Group	RDA Males and Females mcg/day	UL
Children (9–13 years)	600	1,700
Adolescents (14–18 years)	Males: 900	2,800
	Females: 700	
Adults (> 19 years)	Males: 900	3,000
	Females: 700	
*denotes Adequate Intake		

Source: Source: National Institutes of Health, Office of Dietary Supplements. “Dietary Supplement Fact Sheet: Vitamin A.” Last reviewed September 5, 2012. http://ods.od.nih.gov/factsheets/VitaminA-QuickFacts/.

Dietary Sources of Vitamin A

Preformed vitamin A is found only in foods from animals, with the liver being the richest source because that’s where vitamin A is stored (Table 12.5.7). The dietary sources of carotenoids will be given in the following text.

Table 12.5.7: Vitamin A Content of Various Foods

Food	Serving	Vitamin A (IU)	Percent Daily Value
Beef liver	3 oz.	27,185	545
Chicken liver	3 oz.	12,325	245
Milk, skim	1 c.	500	10
Milk, whole	1 c.	249	5
Cheddar cheese	1 oz.	284	6

Source: Source: National Institutes of Health, Office of Dietary Supplements. “Dietary Supplement Fact Sheet: Vitamin A.” Last reviewed July 25, 2012. http://ods.od.nih.gov/factsheets/VitaminA-HealthProfessional/.

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12.6: Selenium and Other Antioxidant Minerals

Learning Objectives

- Describe how selenium is involved in protection of the human body from environmental damage.

While the human body has acquired multiple defenses against free radicals, we also use free radicals to support the functions of some cells. For example, the immune system uses the cell-damaging properties of free radicals to kill pathogens. First, immune cells engulf an invader (such as a bacterium), then they expose it to free radicals such as hydrogen peroxide, which destroys its membrane. The invader is thus neutralized. Scientific studies also suggest hydrogen peroxide acts as a signaling molecule that calls immune cells to injury sites, meaning free radicals may aid with tissue repair when you get cut.

Free radicals are necessary for many other bodily functions as well. The thyroid gland synthesizes its own hydrogen peroxide, which is required for the production of thyroid hormone. Reactive oxygen species and reactive nitrogen species, which are free radicals containing nitrogen, have been found to interact with proteins in cells to produce signaling molecules. The free radical nitric oxide has been found to help dilate blood vessels and act as a chemical messenger in the brain. By acting as signaling molecules, free radicals are involved in the control of their own synthesis, stress responses, regulation of cell growth and death, and metabolism.

Sources of Free Radicals in the Environment

Substances and energy sources from the environment can add to or accelerate the production of free radicals within the body. Exposure to excessive sunlight, ozone, smoke, heavy metals, ionizing radiation, asbestos, and other toxic chemicals increases the number 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.

Selenium

Selenium is an essential trace mineral. It is part of the structure of at least 25 proteins in the body, with functions in reproduction, thyroid hormone metabolism, DNA synthesis, and antioxidant and immune protection.[6] As part of antioxidant enzymes, selenium helps to regenerate other antioxidants, including vitamin C. These enzymes also protect lipids from free radicals, and, in doing so, spare vitamin E. This illustrates how antioxidants work together to protect the body against free radical-induced damage.

Food Sources of Selenium

Organ meats, muscle meats, and seafood have the highest selenium content. Grains and some nuts contain selenium when grown in selenium-containing soils. The selenium content of the soils used to grow animal feed can also affect the selenium content of animal products.

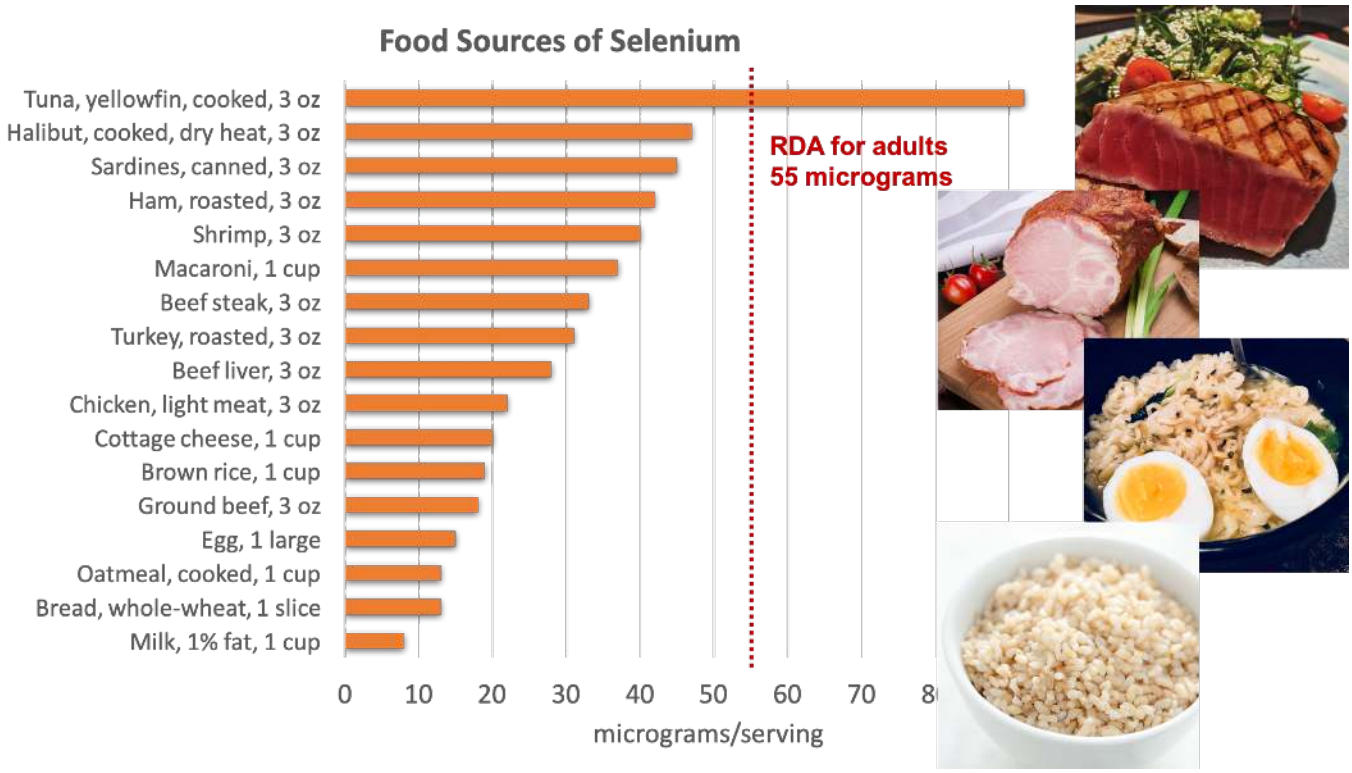


Figure 8.18. Dietary sources of selenium. Source: NIH *Office of Dietary Supplements*

Selenium Deficiency and Toxicity

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.

The Protective Effects of Selenium

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.

Around 25 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.

Dietary Reference Intakes for Selenium

A table that shows the dietary reference intakes for all age groups

Age Group	R.D.A. Males and Females (micrograms per day)	U.L.
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

Selenium at doses several thousand times the RDA can cause acute toxicity, and when ingested in gram quantities can be fatal. Chronic exposure to foods grown in soils containing high levels of selenium (significantly above the UL) can cause brittle hair and nails, gastrointestinal discomfort, skin rashes, halitosis, fatigue, and irritability. The IOM has set the UL for selenium for adults at 400 micrograms per day.

*Table **11.10.2:** Selenium Content of Various Foods*

A table displaying the amount of Selenium content in different food sources

Food	Serving	Selenium (micrograms)	Percent Daily Value
Brazil nuts	1 oz.	544	777
Shrimp	3 oz.	34	49
Crabmeat	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

Oxidative Stress

Oxidative stress refers to an imbalance in any cell, tissue, or organ between the number of free radicals and the capabilities of the detoxifying and repair systems. Sustained oxidative damage results only under conditions of oxidative stress—when the detoxifying and repair systems are insufficient. 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, atherosclerosis (hardening of arteries), arthritis, diabetes, kidney disease, Alzheimer's disease, Parkinson's disease, schizophrenia, bipolar disorder, emphysema, and cataracts.

Aging is a process that is genetically determined but modulated by factors in the environment. In the process of aging, tissue function declines. The idea that oxidative stress is the primary contributor to age-related tissue decline has been around for decades, and it is true that tissues accumulate free radical-induced damage as we age. Recent scientific evidence slightly modifies this theory by suggesting oxidative stress is not the initial trigger for the age-related decline of tissues; it is suggested that the true culprit is progressive dysfunction of metabolic processes, which leads to increases in free radical production, thus influencing the stress response of tissues as they age.

Antioxidant Minerals

In addition to the antioxidant vitamins and phytochemicals, several minerals have antioxidant function, including selenium, manganese, iron, copper, and zinc.

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* concludes 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.Dennert, G. et al. “Selenium for Preventing Cancer.” *Cochrane Database of Systematic Reviews* 5 (2011): CD005195. http://www.ncbi.nlm.nih.gov/pubmed/21563143. 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.

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 12.6.8.

Table 12.6.8: Dietary Reference Intakes for Selenium

Age Group	RDA Males and Females mcg/day	UL
Infants (0–6 months)	15*	45
Infants (7–12 months)	20*	65
Children (1–3 years)	20	90
Children (4–8 years)	30	150
Children (9–13 years)	40	280
Adolescents (14–18 years)	55	400
Adults (> 19 years)	55	400
*denotes Adequate Intake		

Selenium at doses several thousand times the RDA can cause acute toxicity, and when ingested in gram quantities can be fatal. Chronic exposure to foods grown in soils containing high levels of selenium (significantly above the UL) can cause brittle hair and nails, gastrointestinal discomfort, skin rashes, halitosis, fatigue, and irritability. The IOM has set the UL for selenium for adults at 400 micrograms per day.

Dietary Sources of Selenium

Organ meats, muscle meats, and seafood have the highest selenium content. Plants do not require selenium, so the selenium content in fruits and vegetables is usually low. Animals fed grains from selenium-rich soils do contain some selenium. Grains and some nuts contain selenium when grown in selenium-containing soils. See Table 12.6.9 for the selenium content of various foods.

Table 12.6.9: *Selenium Contents of Various Foods*

Food	Serving	mcg
Brazil nuts	1 oz.	544.0
Shrimp	3 oz.	34.0
Crab meat	3 oz.	41.0
Ricotta cheese	1 c.	41.0
Salmon	3 oz.	40.0
Pork	3 oz.	35.0
Ground beef	3 oz.	18.0
Round steak	3 oz.	28.5
Beef liver	3 oz.	28.0
Chicken	3 oz.	13.0
Whole-wheat bread	2 slices	23.0
Couscous	1 c.	43.0
Barley, cooked	1 c.	13.5
Milk, low-fat	1 c.	8.0
Walnuts, black	1 oz.	5.0

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.

Manganese, Iron, Copper, and Zinc: Functions and Health Benefits

As with selenium, manganese, iron, copper, and zinc are essential cofactors for enzymes involved in detoxifying free radicals. In the proper doses they allow for optimal detoxification of free radicals. In excess and when not bound to proteins, manganese, iron, and copper actually accelerate the production of free radicals. This is an attribute of all antioxidants in general, although the effect is greater for certain antioxidants.

Antioxidants can become pro-oxidants when the conditions are altered. Recall that oxidative stress results from an imbalance in free radicals with their detoxifying and repair systems. Another factor that can cause oxidative stress is a high level of antioxidants, as some will revert to acting as pro-oxidants.

Key Takeaways

- Health claims of antioxidant supplements are not backed by scientific evidence and there is some evidence suggesting they cause harm.
- Consuming antioxidant-rich foods is scientifically supported to reduce the risk of chronic diseases.
- Antioxidants have specific functions, and they can act in concert with each other to protect against free radicals.
- Some antioxidants are involved in the regeneration of other antioxidants.
- Many phytochemicals act as antioxidants, but they perform several other functions as well.
- Dietary antioxidants and phytochemicals in the proper doses are beneficial to health but can cause harm in excess.

Discussion Starters

1. In regard to doses, discuss why it is better to obtain antioxidants from the diet and not from supplements. When might supplements be advantageous?
2. With more scientific evidence in hand, debate whether or not the supplement industry requires more regulation.

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12.7: Phytochemicals

Phytochemicals are chemicals in plants that may provide some health benefit. 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 12.7.1: 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.

Phytochemicals

Phytochemicals are chemicals in plants that may provide some health benefit. 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.

Carotenoids Function and Health Benefits

Carotenoids are pigments synthesized by plants that give them their yellow, orange, and red color. Over six hundred carotenoids have been identified and, with just a few exceptions, all are found in the plant kingdom. There are two classes of carotenoids—the xanthophylls, which contain oxygen, and the carotenes, which do not.

In plants, carotenoids absorb light for use in photosynthesis and act as antioxidants. Beta-carotene, alpha-carotene, gamma-carotene, and beta-cryptoxanthin are converted to some extent to retinol in the body. The other carotenoids, such as lycopene, are not. Many biological actions of carotenoids are attributed to their antioxidant activity, but they likely act by other mechanisms, too.

Eye Conditions

Lutein, found in green leafy vegetables, and zeaxanthin, found in peppers, corn, and saffron, act as antioxidants in the retina of the eye and protect it from ultraviolet light damage. Diets high in these carotenoids are associated with a decreased risk of AMD, and there is good evidence that supplements containing these carotenoids also provide vision benefits. A review published in the August 2010 issue of *Current Medical Research and Opinion* concludes that supplementation with lutein and zeaxanthin reduces the incidence of AMD and cataracts.Barker II, F. M. “Dietary Supplementation: Effects on Visual Performance and Occurrence of AMD and Cataracts.” *Curr Med Res Opin* 26, no. 8 (2010): 2011–23. http://informahealthcare.com/doi/abs...95.2010.494549.

The data that supports that beta-carotene supplementation may delay the progression of AMD is more convincing when beta-carotene is taken in combination with other micronutrients. The Age-Related Eye Disease Study found that a supplement containing 500 milligrams of vitamin C, 400 international units of vitamin E, 15 milligrams of beta-carotene, 80 milligrams of zinc oxide, and 2 milligrams of copper as cupric oxide reduced the risk of progressing to advanced stages of AMD by 25 percent.Age-Related Eye Disease Study Research Group. “A Randomized, Placebo-Controlled, Clinical Trial of High-Dose Supplementation with Vitamins C and E, Beta-Carotene, and Zinc for Age-Related Macular Degeneration and Vision Loss.” *Arch Ophthalmol* 119, no. 10 (2001): 1417–36. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1462955/. This study did not find that the formulated supplement significantly prevented the onset of disease, only that it delayed its progression specifically in people with intermediate or advanced stage AMD. Studies are ongoing to determine if other antioxidant combinations actually protect against developing AMD at all.

Cardiovascular Disease

While some studies do associate a decreased risk for atherosclerosis with higher dietary intake of carotenoids, others do not. There is a large number of studies that show total carotenoid intake is associated with improvement in blood vessel function. A smaller number of studies show that intake of specific carotenoids, such as lycopene and alpha-carotene, are also associated with improved blood vessel function. The main problems associated with linking carotenoids to a decrease in cardiovascular disease risk, or any other disease for that matter, are that they are present in foods containing many other beneficial plant chemicals, and trials evaluating the effects of specific carotenoids in the form of supplements provide inconsistent and sometimes contradictory results.

Cancer

A higher intake of some carotenoids, but not others, is linked to decreased risks for some cancers. A review of two large studies (> 120,000 men and women) published in the October 2000 issue of *The American Journal of Clinical Nutrition* reports that there is no significant association between beta-carotene intake and lung cancer risk, but men and women with the highest intakes of total carotenoids had a more than 30 percent risk reduction for developing lung cancer.Michaud, D.S. et al. “Intake of Specific Carotenoids and Risk of Lung Cancer in 2 Prospective US Cohorts.” *Am J Clin Nutr* 72, no. 4 (2000): 990–97. http://www.ajcn.org/content/72/4/990.long. Other large studies conducted in Europe have confirmed the inverse relationship of total dietary carotenoid intake with lung cancer risk. There is some evidence that diets rich in lycopene, which is present in high concentrations in tomatoes, is linked to decreased prostate cancer risk, but it is not known if it is lycopene specifically or some other component in tomatoes that protects against prostate cancer.

Carotenoid Bioavailability and Dietary Sources

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

In contrast to most micronutrients, carotenoid availability is actually increased by the cooking process because cooking, along with chopping and homogenizing, releases carotenoids from the plant matrix. Thus, eating a can of tomatoes provides more lycopene than eating a raw tomato. However, overcooking transforms some of the carotenoids into inactive products, and in general it is best to chop and lightly steam vegetables containing carotenoids to maximize their availability from foods. Cooking carotenoid-containing foods in oil also enhances the bioavailability of carotenoids. In the United States, the most consumed carotenoids are alpha-carotene, beta-carotene, beta-cryptoxanthin, lycopene, lutein, and zeaxanthin. See Table 12.7.7 for the carotenoid content of various foods.

Table 12.7.7: Alpha- and Beta-Carotene Content of Various Foods

Food	Serving	Beta-carotene (mg)	Alpha-carotene (mg)
Pumpkin, canned	1c.	17.00	11.70
Carrot juice	1c.	22.00	10.20
Carrots, cooked	1c.	13.00	5.90
Carrots, raw	1 medium	5.10	2.10
Winter squash, baked	1c.	5.70	1.40
Collards, cooked	1c.	11.60	0.20
Tomato	1 medium	0.55	0.10
Tangerine	1 medium	0.13	0.09
Peas, cooked	1c.	1.20	0.09

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.

Interactive 12.7.1

Visit the USDA website and find out more about the carotenoid content of various foods: http://www.ars.usda.gov/Services/docs.htm?docid=20958

Three Other Phytochemicals and Their Potential Health Benefits

Three classes of phytochemicals (other than carotenoids) are flavonoids, organosulfur compounds, and lignans. Their potential health benefits are discussed below.

Flavonoids

Flavonoids are a large class of chemicals including anthocyanidins (found in red, blue, and purple berries), flavanols (found in teas, chocolate, berries, apples, yellow onions, kale, and broccoli), and isoflavones (found in soy products). Flavonoids are very effective free radical scavengers, and there is some evidence that higher intakes of flavonoid-rich foods and/or beverages reduce the risk of cardiovascular disease, but this has not been consistently observed. Although flavonoids have been shown to reduce the incidence of some tumors in animals, similar studies in humans have been inconclusive.

Organosulfur Compounds

These compounds are predominantly found in garlic, but can also be found in onions and leeks. It's suspected that the higher intake of garlic is the aspect of the Mediterranean diet that contributes to a decreased risk of cardiovascular disease. Animal and laboratory studies suggest the organosulfur compounds in garlic reduce cholesterol, are anti-inflammatory, stimulate the synthesis of glutathione, and cause death of cancer cells. There is some evidence in humans that garlic reduces cholesterol, but more recent

studies did not confirm that the effect was signficant or sustained. A higher intake of garlic likely inhibits blood clot formation in humans.

Observational studies suggest diets high in organosulfur compounds decrease the risk of gastric and colorectal cancer. For other cancers, the data is less consistent.

Lignans

Lignans are a group of chemical compounds obtained from many food sources, including grains, nuts, seeds, fruits, and vegetables, and especially flax seed. Some lignans are also called phytoestrogens as they can mimic or inhibit some of the actions of the hormone estrogen in the body. The antiestrogenic effect of some lignans suggests they may be helpful in treating hormone-dependent cancers, such as breast and ovarian cancers. However, studies are few and conflicting on whether eating foods high in lignans reduces breast or ovarian cancer. In regard to cardiovascular disease risk, diets rich in whole grains are protective, but it remains unclear whether it is the lignans in whole grains that are responsible for the reduced risk. Whole grains contain many other beneficial phytochemicals, micronutrients, and fiber.

Interactive 12.7.2

To discover more about phytochemicals, visit the website for the Micronutrient Information Center of the Linus Pauling Institute at Oregon State University: http://lpi.oregonstate.edu/infocenter/phytochemicals.html

Other Dietary Sources of Beneficial Phytochemicals

Herbs and Spices

These are the aromatic parts of plants, such as the leaves, seeds, pods, and berries. They are an additional dietary source of phytochemicals, and many have exceptional antioxidant capacity.

Throughout the ages, people have used spices and herbs not only for adding flavor to foods, but also as medicines. Curcumin, the principal component of tumeric, has been used for over two thousand years in India to treat a variety of ailments. As of 2011, over seventy clinical trials are investigating the health benefits of curcumin, which may include reducing cancer risk and delaying the progression of Alzheimer's disease.

You learned in the beginning of this chapter that nutmeg comes from the dried seed kernel of *Myristica fragrans* and has been used as an antimicrobial, antifungal, and anti-inflammatory agent, and as a pain reliever. In high doses nutmeg acts similar to a psychoactive drug in that it causes euphoria, delusions, and hallucinations. According to a study conducted on over 3,100 foods, beverages, spices, herbs, and supplements, the spices and herbs were the dietary sources most rich in antioxidants.

Interactive 12.7.3

Read the article, "The Total Antioxidant Content of More than 3,100 Foods, Beverages, Spices, Herbs, and Supplements Used Worldwide," published in the January 2010 issue of the *Nutrition Journal*. It is a useful source to find dietary sources of antioxidants.

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2841576/?tool=pubmed

Tools for Change

Add some spice, flavor, and decoration to your food along with beneficial antioxidants and phytochemicals. Embracing cuisine rich in spices and herbs further enhances the health benefits of eating a diet rich in fruit and vegetables. Think spices are too hot for your palate? As little as half a teaspoon of cinnamon has been shown in scientific studies to provide health benefits, such as improving glucose homeostasis in people with Type 2 diabetes. Over fifteen clinical trials are now evaluating the effectiveness of cinnamon as a adjunct treatment for Type 2 diabetes and/or cardiovascular disease.

Tea

Tea is an aromatic beverage made from the dried parts of plants steeped in hot water. Its health benefits have been known for years, and as with coffee the benefits are not just physiological, but also mental and social. In folklore, teas are considered curatives of stomachache, diarrhea, and even the plague. In *The Book of Tea*, Okakura Kakuzo asserts that consuming a cup of tea provides "the

adoration of the beautiful among the sordid facts of everyday existence."Okakura Kakuzo. *The Book of Tea*. (Berlin, Germany: Dover Publications, 1964).

Teas can contain more than seven hundred different phytochemicals. Some of them may be beneficial and others may not be, as some reduce the dietary absorption of some micronutrients. The health claims of drinking tea—black, green, or red—number at least in the hundreds but remain mostly scientifically unsupported. There are a great number of studies showing that drinking tea is at least linked to a decreased risk of heart disease, cancer, and diabetes, but the exact phyotchemicals illiciting these health benefits are under intense scrutiny. Moreover, people who consume more tea are likely to drink fewer soft drinks and therefore, based on a "replacement theory," have a reduced likelihood of having a chronic disease.

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Attributions

- Hawaii

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12.8: The Whole Nutrient Package versus Disease

Learning Objectives

- List some of the health-related conditions that might be mitigated by eating antioxidant- and phytochemical-rich foods regularly.
- Explain the importance of eating a variety of fruits, vegetables, nuts, legumes, teas, and grains to obtain antioxidants and phytochemicals.



Figure 12.8.1: Forget the antioxidant-pill hype and get all of the health benefits from antioxidants and phytochemicals by eating a variety of fruits and vegetables. © Thinkstock

A healthy diet incorporating seven or more servings of fruits and vegetables has been shown in many scientific studies to reduce cardiovascular disease and overall deaths attributable to cancer. The WHO states that insufficient fruit and vegetable intake is linked to approximately 14 percent of gastrointestinal cancer deaths, about 11 percent of heart attack deaths, and 9 percent of stroke deaths globally.World Health Organization. “Global Strategies on Diet, Physical Activity, and Health.” Accessed September 30, 2011. http://www.who.int/dietphysicalactivity/fruit/en/index.html. The WHO estimates that, overall, 2.7 million deaths could be avoided annually by increasing fruit and vegetable intake. These preventable deaths place an economic, social, and mental burden on society. This is why, in 2003, the WHO and the Food and Agricultural Organization of the United Nations launched a campaign to promote fruit and vegetable intake worldwide.

In the last section we reviewed the health benefits of particular antioxidants and phytochemicals obtained from fruits and vegetables and discovered that naturally incorporating them in the diet rather than taking supplements is best. Here we will consider the scientific evidence that diets rich in antioxidants actually lower chronic disease risk.

Antioxidant Variety in Food Provides Health Benefits

Not only has the several-billion-dollar supplement industry inundated us with FDA-unapproved health claims, but science is continously advancing and providing us with a multitude of promising health benefits from particular fruits, vegetables, teas, herbs, and spices. For instance, blueberries protect against cardiovascular disease, an apple or pear a day reduces stroke risk by over 52 percent, eating more carrots significantly reduces the risk of bladder cancer, drinking tea reduces cholesterol and helps glucose homeostasis, and cinnamon blocks infection and reduces the risk of some cancers. However, recall that science also tells us that no one nutrient alone is shown to provide these effects.

What micronutrient and phytochemical sources are best at protecting against chronic disease? All of them, together. Just as there is no wonder supplement or drug, there is no superior fruit, vegetable, spice, herb, or tea that protects against all diseases. A review in the July–August 2010 issue of *Oxidative Medicine and Cellular Longevity* concludes that the plant-food benefits to health are attributed to two main factors—that nutrients and phytochemicals are present at low concentrations in general, and that the complex mixtures of nutrients and phytochemicals provides additive and synergistic effects.Bouayed, J. and T. Bohn. “Exogenous Antioxidants—Double-Edged Swords in Cellular Redox State: Health Beneficial Effects at Physiologic Doses versus Deleterious Effects at High Doses.” *Oxidative Medicine and Cellular Longevity* 3, no. 4 (2010): 228–37. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2952083/?tool=pubmed. In short, don’t overdo it with supplements and make sure you incorporate a wide variety of nutrients in your diet.

Eating a variety of fruits and vegetables rich in antioxidants and phytochemicals promotes health. Consider these diets:

- **Mediterranean diet.** Fresh fruit and vegetables are abundant in this diet, and the cultural identity of the diet involves multiple herbs and spices. Moreover, olive oil is the main source of fat. Fish and poultry are consumed in low amounts and red meat is consumed in very low amounts. An analysis of twelve studies involving over one million subjects published in the September 2008 issue of the *British Medical Journal* reports that people who followed the Mediterranean diet had a 9 percent decrease in overall deaths, a 9 percent decrease in cardiovascular death, a 6 percent decrease in cancer deaths, and a 13 percent reduced incidence of Parkinson's disease and Alzheimer's disease.Sofi, F. et al. "Adherence to Mediterranean Diet and Health Status: Meta-Analysis." *Br Med J* 337 (2008): a1344. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2533524/. The authors of this study concluded that the Mediterranean diet is useful as a primary prevention against some major chronic diseases.
- **Dietary Approaches to Stop Hypertension (DASH diet).** Recall from Chapter 7 that 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. Results from a follow-up study published in the December 2009 issue of the *Journal of Human Hypertension* suggest the low-sodium DASH diet reduces oxidative stress, which may have contributed to the improved blood vessel function observed in salt-sensitive people (between 10 to 20 percent of the population).Al-Solaiman, Y. et al. "Low-Sodium DASH Reduces Oxidative Stress and Improves Vascular Function in Salt-Sensitive Humans." *J Hum Hypertens* 12 (2009): 826–35. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2783838/?tool=pubmed.
- **Diets high in fruits and vegetables.** An analysis of The Nurses' Health Study and the Health Professionals' Follow-up Study reported that for every increased serving of fruits or vegetables per day, especially green leafy vegetables and vitamin C-rich fruits, there was a 4 percent lower risk for heart disease.Joshipura, K.J. et al. "The Effect of Fruit and Vegetable Intake on Risk for Coronary Heart Disease." *Ann Intern Med* 134, no. 12 (2001): 1106–14. http://www.ncbi.nlm.nih.gov/pubmed/11412050.

Americans Typically Eat Fewer than the Recommended Servings of Fruits and Vegetables

An article in the January 2009 issue of the *Medscape Journal of Medicine* reports that fewer than one in ten Americans consumes the recommended amount of fruits and vegetables, which is between five and thirteen servings per day.Kimmons, J. et al. "Fruit and Vegetable Intake among Adolescents and Adults in the United States: Percentage Meeting Individualized Recommendations." *Medscape Journal of Medicine* 11, no. 1 (2009): 26. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2654704/?tool=pubmed. According to this study, the largest single contributor to fruit intake was orange juice, and potatoes were the dominant vegetable.

The USDA recommends that you fill half your plate with fruits and vegetables. The number of servings of fruits and vegetables that a person should consume every day is dependent on age, sex, and level of physical activity. For example, a forty-year-old male who exercises for sixty minutes per day should consume 2 cups of fruit and 3½ cups of vegetables, while a fifteen-year-old female who exercises for thirty minutes per day should consume 1½ cups of fruit and 2½ cups of vegetables. (One cup of a fruit or vegetable is equal to one banana, one small apple, twelve baby carrots, one orange, or one large sweet potato.) To find out the amount of fruits and vegetables the Centers for Disease Control and Prevention (CDC) recommends.

Interactive 12.8.1

The CDC provides a fruit- and vegetable-intake calculator. www.fruitsandveggiesmatter.gov/form.html

Improving Fruit and Vegetable Intake at Home and in Your Community

Eating more fruits and vegetables can make you think better, too. According to a study published in 2009 in the *Journal of Alzheimer's Disease*, no matter your age, eating more fruits and vegetables improves your brain function.Polidori, M.C. et al. "High Fruit and Vegetable Intake Is Positively Correlated with Antioxidant Status and Cognitive Performance in Healthy Subjects." *Journal of Alzheimer's Disease* 17, no. 4 (2009): 921–7. http://www.ncbi.nlm.nih.gov/pubmed/19542607. Check out Note 8.26 "Interactive 8.5" for thirteen fun ways to increase your fruit and vegetable intake.

Interactive 12.8.2

Visit the University of Nebraska-Lincoln's website to discover thirteen fun ways to increase your fruit and vegetable intake. http://food.unl.edu/web/fnh/freezer-bags

For individually based strategies on how to stretch your fruit and vegetable budget see Interactive 12.8.3.

Interactive 12.8.3

The Department of Health and Human Services provides "30 Ways in 30 Days to Stretch Your Fruit and Vegetable Budget." www.fruitsandveggiesmatter.go..._FV_Budget.pdf

Tools for Change

Accept the challenge of optimizing your fruit and vegetable intake. Make it easier on your wallet by choosing five of the thirty ways to stretch your fruit and vegetable budget, and implement them in the next seven days.

The CDC has developed seven strategies to increase American's intake of fruits and vegetables.Centers for Disease Control and Prevention. "The CDC Guide to Fruit and Vegetable Strategies to Increase Access, Availability, and Consumption." March 2010. www.cdph.ca.gov/SiteCollectio...onsumption.pdf.

1. Support local and state governments in the implementation of a Food Policy Council, which develops policies and programs that increase the availability of affordable fruits and vegetables.
2. In the food system, increase the availability and affordability of high-quality fruits and vegetables in underserved populations.
3. Promote farm-to-where-you-are programs, which is the delivery of regionally grown farm produce to community institutions, farmers markets, and individuals.
4. Encourage worksites, medical centers, universities, and other community and business establishments to serve more fruits and vegetables in cafeterias and onsite eateries.
5. Support schools in developing healthy food messages to students by incorporating activities such as gardening into curricula.
6. Encourage the development and support of community and home gardens.
7. Have emergency food programs, including food banks and food rescue programs, increase their supply of fruits and vegetables.

The seven strategies developed by the CDC are based on the idea that improving access to and availability of fruits and vegetables will lead to an increase in their consumption.

Key Takeaways

- Antioxidants and phytochemicals from fruits and vegetables are thought to reduce disease risk.
- Antioxidants and phytochemicals may be beneficial in low doses but not in high doses.
- Eat a variety of foods rich in micronutrient antioxidants and phytochemicals to promote health.
- Fewer than one in ten Americans consumes the recommended amount of fruits and vegetables, which is between five and thirteen servings per day.
- National and international campaigns aim to increase the intake of fruits and vegetables worldwide.

Discussion Starters

1. Discuss the various strategies you use, or plan to use, to increase the amount of fruits and vegetables in your diet. Learn other interesting and fun ways to do so from your peers.
2. Share with your classmates your favorite spices, how you use them, and where you buy them.

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12.9: Exercises - Antioxidants

It's Your Turn

1. Use the fruit- and vegetable-intake calculator provided by the CDC to determine the amount of fruit and vegetables recommended for your diet, and then plan a menu for a day that incorporates the recommended amount of fruits and vegetables. www.fruitsandveggiesmatter.gov/form.html
2. The next time you're at the grocery store, record the number, color, and names of the fruits and vegetables available. Draw a table of them, sorted by color. Write a brief statement on whether you have access to an affordable variety of fruits and vegetables.
3. Visit the website "Nutrition-and-You" and choose three herbs and/or spices to write a brief summary on, including the plant they come from, their potential health benefits, and how they are used in foods. http://www.nutrition-and-you.com/healthy_spices.html

Apply It

1. Visit the Oldways website at http://www.oldwayspt.org/mediterranean-diet-pyramid and construct a pyramid of the Mediterranean diet.

Expand Your Knowledge

1. Read the article, "Antioxidant Content of Whole-Grain Breakfast Cereals, Fruits, and Vegetables" in the *Journal of the American College of Nutrition* (http://www.jacn.org/content/19/suppl_3/312S.long) and summarize in a paragraph the unique phytochemical profile and antioxidant capacity of whole grains.
2. Find out how much fruit and vegetables cost by reviewing this document published by the USDA (www.ers.usda.gov/Publications/EIB71/EIB71.pdf), and make a chart of the costs of your favorite fruits and vegetables.

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12.10: Research Highlight - Cancer

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... In the following publication... 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

APA citation

Further evaluation

To evaluate this publication further, it might help to...

References

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12.11: EDIT Vitamins As Antioxidants - An Introduction

The Vitamins

Vitamins are organic compounds that are traditionally assigned to two groups: fat-soluble(hydrophobic) or water-soluble (hydrophilic).

- The fat-soluble vitamins include vitamins A, D, E, K.
- The water-soluble vitamins include the B vitamins and vitamin C.
- This classification determines where they act in the body. The fat-soluble vitamins are largely responsible for protecting cell membranes from free radical damage. The water-soluble vitamins act in the cytosol of cells or in extracellular fluids such as blood; The body can synthesize some vitamins, but others must be obtained from the diet.
- Another important difference between fat-soluble vitamins and water-soluble vitamins is the way they are absorbed in the body. Vitamins are absorbed primarily in the small intestine and their bio-availability is dependent on the food composition. Including a small amount of fat or oil in your meal can enhance fat-soluble vitamin absorption.
- Once fat-soluble vitamins have been absorbed in the small intestine, they are packaged and incorporated into chylomicrons along with other fatty acids
  and transported in the lymphatic system to the liver.
- Water-soluble vitamins, on the other hand, are absorbed in the small intestine but are transported to the liver through blood vessels.
- Vitamins are obtained from the different types of foods that we consume. If a diet is lacking a certain type of nutrient, a vitamin deficiency may occur.

The Antioxidant Vitamin A

Vitamin A is a generic term for a group of similar compounds called retinoids. Every vitamin has a biologically active form that plays a very important role in Nutrition. Retinol is the form of vitamin A found in animal-derived foods and is converted in the body to the biologically active forms of vitamin A: retinal and retinoic acid (thus retinol is sometimes referred to as “preformed vitamin A”). About 10 percent of plant-derived carotenoids, including beta-carotene, can be converted in the body to retinoids and are another source of functional vitamin A. Carotenoids are pigments synthesized by plants that give them their yellow, orange, and red color. Over six hundred carotenoids have been identified and, with just a few exceptions, all are found in the plant kingdom. There are two classes of carotenoids—the xanthophylls, which contain oxygen, and the carotenes, which do not.

In plants, carotenoids absorb light for use in photosynthesis and act as antioxidants. Beta-carotene, alpha-carotene, and beta-cryptoxanthin are converted to some extent to retinol in the body. The other carotenoids, such as lycopene, are not. Many biological actions of carotenoids are attributed to their antioxidant activity, but they likely act by other mechanisms, too.

Vitamin A is fat-soluble and is packaged into chylomicrons in the small intestine, and transported to the liver. The liver stores and exports vitamin A as needed; it is released into the blood and is transported to cells. Carotenoids are not absorbed as well as vitamin A, but similar to vitamin A, they do require fat in the meal for absorption. In intestinal cells, carotenoids are packaged into the lipid-containing chylomicrons and then transported to the liver. In the liver, carotenoids are repackaged into lipoproteins, which transport them to cells.

The retinoids are aptly named as their most notable function is in the retina of the eye where they aid in vision, particularly in seeing under low-light conditions. This is why night blindness is the most definitive sign of vitamin A deficiency. Vitamin A has several important functions in the body, including maintaining vision and a healthy immune system. Many of vitamin A’s functions in the body are similar to the functions of hormones (for example, vitamin A can interact with DNA, causing a change in protein function). Vitamin A assists in maintaining healthy skin and the linings and coverings of tissues; it also regulates growth and development. As an antioxidant, vitamin A protects cellular membranes, helps in maintaining glutathione levels, and influences the amount and activity of enzymes that detoxify free radicals.

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

Some carotenoids are converted to retinol in the body by intestinal cells and liver cells. However, only minuscule amounts of certain carotenoids are converted to retinol, meaning fruits and vegetables are not necessarily good sources of vitamin A.

The Dietary Sources and Measurements

The R.D.A. for vitamin A includes all sources of vitamin A. The R.D.A. for vitamin A is given in mcg of retinol activity requirements (R.A.E.) to take into account the many different forms it is available in. The human body converts all dietary sources of vitamin A into retinol. Therefore, 1 mcg of retinol is equivalent to 12 mcg of beta-carotene, and 24 mcg of alpha-carotene or beta-cryptoxanthin. For example, 12 micrograms of fruit- or vegetable-based beta-carotene will yield 1 microgram of retinol. Currently, vitamin A listed in food and on supplement labels use international units (I.U.s). The following conversions are listed below[3:]

- 1 I.U. retinol = 0.3 mcg R.A.E.
- 1 I.U. beta-carotene from dietary supplements = 0.15 mcg R.A.E.
- 1 I.U. beta-carotene from food = 0.05 mcg R.A.E.
- 1 I.U. alpha-carotene or beta-cryptoxanthin = 0.025 mcg R.A.E.

The R.D.A. for vitamin A is considered sufficient to support growth and development, reproduction, vision, and immune system function while maintaining adequate stores (good for four months) in the liver.

Sources of Beta-Carotene

In the United States, the most consumed carotenoids are alpha-carotene, beta-carotene, beta-cryptoxanthin, lycopene, lutein, and zeaxanthin.

Food	Serving	Vitamin A (I.U.)	Percent Daily Value
Pumpkin, canned	1c.	17.00	11.70
Carrot juice	1c.	22.00	10.20
Carrots, cooked	1c.	13.00	5.90
Carrots, raw	1 medium	5.10	2.10
Winter squash, baked	1c.	5.70	1.40
Collards, cooked	1c.	11.60	0.20
Tomato	1 medium	0.55	0.10
Tangerine	1 medium	0.13	0.09
Peas, cooked	1c.	1.20	0.09

The Antioxidant Vitamin E

Vitamin E occurs in eight chemical forms, of which alpha-tocopherol appears to be the only form that is recognized to meet human requirements. Alpha-tocopherol and vitamin E's other constituents are fat-soluble and primarily responsible for protecting cell membranes against lipid destruction caused by free radicals, therefore making it an antioxidant. When alpha-tocopherol interacts with a free radical it is no longer capable of acting as an antioxidant unless it is enzymatically regenerated. Vitamin C helps to regenerate some of the alpha-tocopherol, but the remainder is eliminated from the body. Therefore, to maintain vitamin E levels, you must ingest it as part of your diet.

Insufficient levels are rare (signs and symptoms of such conditions are not always evident) but are primarily the result of nerve degeneration. People with malabsorption disorders, such as Crohn's disease or cystic fibrosis, and babies born prematurely, are at higher risk for vitamin E deficiency.

Vitamin E has many other important roles and functions in the body such as boosting the immune system by helping to fight off bacteria and viruses. It also enhances the dilation of blood vessels and inhibits the formation of blood clotting. Despite vitamin E's numerous beneficial functions when taken in recommended amounts, large studies do not support the idea that taking higher doses of this vitamin will increase its power to prevent or reduce disease risk.

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

Dietary Reference Intakes for Vitamin E

A table that shows dietary reference intakes of vitamin E for several different age ranges.

Age Group	R.D.A. Males and Females (m.g. Per Day)	U.L.
Infants (0–6 months)	4*	*None*
Infants (7–12 months)	5*	*None*
Children (1–3 years)	6	200
Children (4–8 years)	7	300
Children (9–13 years)	11	600
Adolescents (14–18 years)	15	800
Adults (> 19 years)	15	1,000

Vitamin E is found in many foods, especially those higher in fat, such as nuts and oils. Some spices, such as paprika and red chili pepper, and herbs, such as oregano, basil, cumin, and thyme, also contain vitamin E. (Keep in mind spices and herbs are commonly used in small amounts in cooking and therefore are a lesser source of dietary vitamin E.)

Dietary Sources of Vitamin E

A table that shows dietary sources of vitamin E.

Food	Serving Size	Vitamin E (M G)	Percent Daily Value
Sunflower seeds	1 oz.	7.4	37
Almonds	1 oz.	6.8	34
Sunflower oil	1 Tbsp	5.6	28
Hazelnuts 1 oz.	1 oz.	4.3	22
Peanut butter	2 Tbsp.	2.9	15
Peanuts 1 oz.	1 oz.	2.2	11
Corn oil 1 Tbsp.	1 Tbsp.	1.9	10
Kiwi	1 medium	1.1	6
Tomato	1 medium	0.7	4
Spinach	1 c. raw	0.6	3

The Antioxidant Vitamin C

Vitamin C, also commonly called ascorbic acid, is a water-soluble micronutrient essential in the diet for humans, although most other mammals can readily synthesize it. Vitamin C's ability to easily donate electrons makes it a highly effective antioxidant. It is effective in scavenging free radicals. It protects lipids both by disabling free radicals and by aiding in the regeneration of vitamin E.

In addition to its role as an antioxidant, vitamin C is a required part of several enzymes like signaling molecules in the brain, some hormones, and amino acids. Vitamin C is also essential for the synthesis and maintenance of collagen. Collagen is the most abundant protein in the body and used for different functions such as the structure for ligaments, tendons, and blood vessels and also scars that bind wounds together. Vitamin C acts as the glue that holds the collagen fibers together and without sufficient levels in the body, collagen strands are weak and abnormal.

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

The classic condition associated with vitamin C deficiency is scurvy. The signs and symptoms of scurvy include skin disorders, bleeding gums, painful joints, weakness, depression, and increased susceptibility to infections. Scurvy is prevented by having an adequate intake of fruits and vegetables rich in vitamin C.

Vitamin C's ability to prevent disease has been debated for many years. Overall, higher dietary intakes of vitamin C (via food intake, not supplements), are linked to decreased disease risk. A review of multiple studies published in the January issue of Nutrition Research concludes there is a limited role for vitamin C supplementation in certain population groups (older people, individuals with lower Vitamin C status, those at higher risk of cardiovascular disease) to improve cardiovascular health. Vitamin C levels in the body have been shown to correlate well with fruit and vegetable intake, and higher plasma vitamin C levels are linked to a reduced risk of some chronic diseases.

There is some evidence that a higher vitamin C intake is linked to a reduced risk of cancers of the mouth, throat, esophagus, stomach, colon, and lung, but not all studies confirm this is true. As with the studies on cardiovascular disease, the reduced risk of cancer is the result of eating foods rich in vitamin C, such as fruits and vegetables, not from taking vitamin C supplements. In these studies, the specific protective effects of vitamin C cannot be separated from the many other beneficial chemicals in fruits and vegetables.

Vitamin C does have several roles in the immune system, and many people increase vitamin C intake either from diet or supplements when they have a cold. Many others take vitamin C supplements routinely to prevent colds. Contrary to this popular practice, however, there is no good evidence that vitamin C prevents a cold. A review of more than fifty years of studies published in 2004 in the Cochrane Database of Systematic Reviews concluded that taking vitamin C routinely does not prevent colds in most people, but it does slightly reduce cold severity and duration. Moreover, taking mega doses (up to 4 grams per day) at the onset of a cold provides no benefits.[2]

Gout is a disease caused by elevated circulating levels of uric acid and is characterized by recurrent attacks of tender, hot, and painful joints. There is some evidence that a higher intake of vitamin C reduces the risk of gout.

Dietary Reference Intakes for Vitamin C

A table that shows dietary reference intakes of vitamin C for several different age ranges.

Age Group	R.D.A. Males and Females (Milligrams Per Day)	U.L.
Infants (0–6 months)	40*	*None*
Infants (7–12 months)	50*	*None*
Children (1–3 years)	15	400
Children (4–8 years)	25	650
Children (9–13 years)	45	1200
Adolescents (14–18 years)	75 (males), 65 (females)	1800
Adults (> 19 years)	90 (males), 75 (females)	2,000

Citrus fruits are great sources of vitamin C and so are many vegetables. In fact, British sailors in the past were often referred to as "limeys" as they carried sacks of limes onto ships to prevent scurvy. Vitamin C is not found in significant amounts in animal-based foods. Because vitamin C is water-soluble, it leaches away from foods considerably during cooking, freezing, thawing, and canning. Up to 50 percent of vitamin C can be boiled away. Therefore, to maximize vitamin C intake from foods, you should eat fruits and vegetables raw or lightly steamed.

Vitamin C Content of Various Foods

A table that shows dietary sources for vitamin C

Food	Serving	Vitamin C (milligrams)	Percent Daily Value
Orange juice	6 oz.	93	155
Grapefruit juice	6 oz.	70	117

Orange	1 medium	70	117
Strawberries	1 c.	85	164
Tomato	1 medium	17	28
Sweet red pepper	½ c. raw	95	158
Broccoli	½ c. cooked	51	65
Romaine lettuce	2 c.	28	47
Cauliflower	1 c. boiled	55	86
Potato	1 medium, baked	17	28

Source: Dietary Supplement Fact Sheet: Vitamin C. National Institutes of Health, Office of Dietary Supplements.

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CHAPTER OVERVIEW

13: Nutrients Important for Bone Health

13.1: Introduction to Bone Health

13.2: Calcium- Critical for Bones and Throughout the Body

13.3: Other Minerals Important to Bone Health

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13.1: 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. ***Compact bone*** (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.

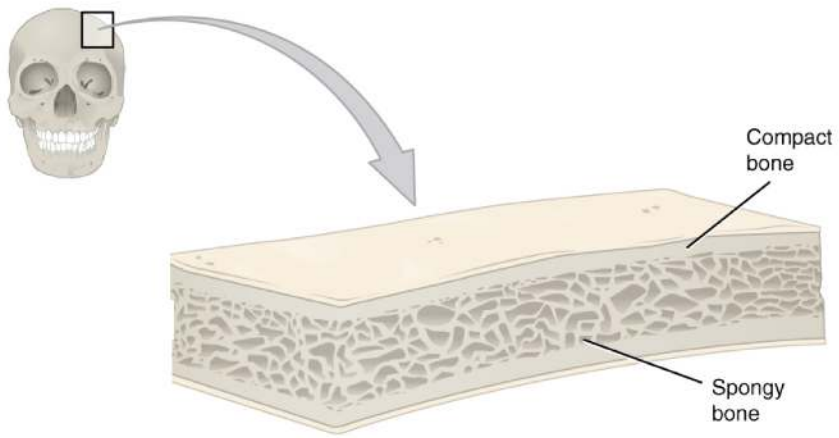


Figure 13.1.1: This cross-section of a flat bone from the skull shows the spongy bone lined on either side by a layer of compact bone. "Anatomy of a Flat Bone" by J. Gordon Betts, Kelly A. Young, James A. Wise, Eddie Johnson, Brandon Poe, Dean H. Kruse, Oksana Korol, Jody E. Johnson, Mark Womble, Peter DeSaix, Anatomy and Physiology, OpenStax, licensed under CC BY 4.0

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]

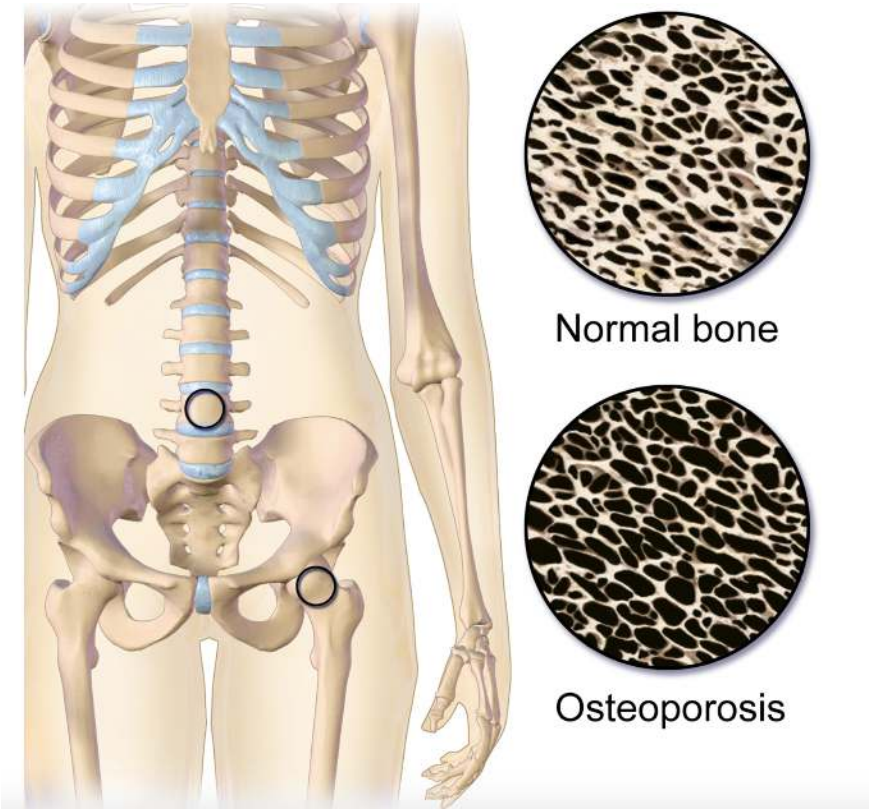


Figure 13.1.2: Osteoporosis. This illustration shows the difference between the structure of normal bone, which is less porous, and bone with osteoporosis, which is more porous. The two circles located on the spine and hip represent the location of the images. "Osteoporosis" by BruceBlaus is licensed under CC BY-SA

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 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.

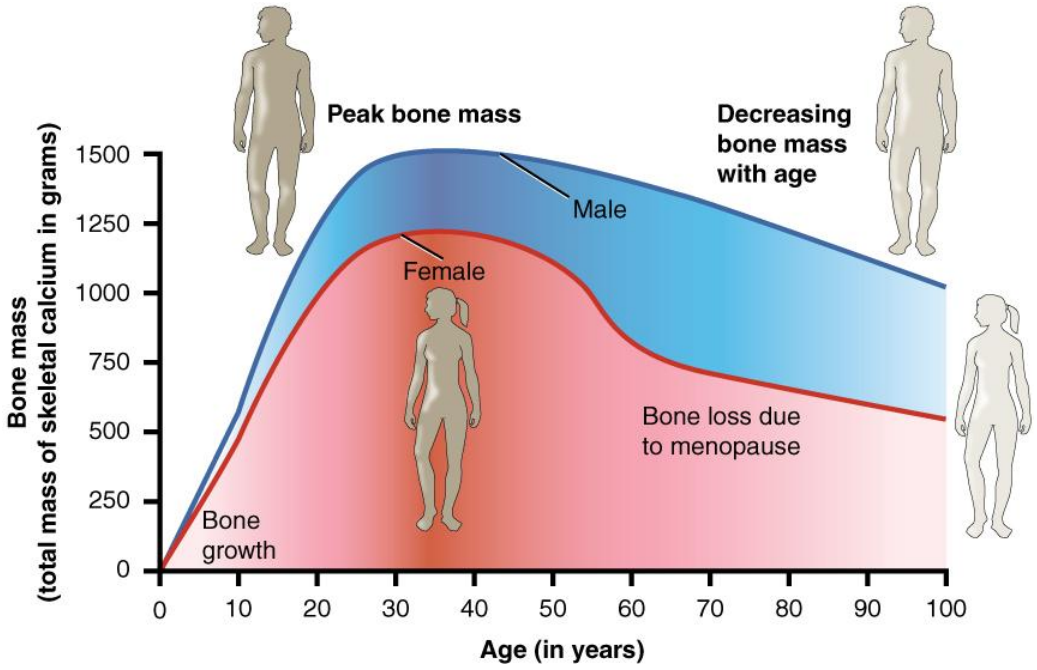


Figure 13.1.3: Age and bone mass. Bone density peaks at about *30 years of age , and women lose bone mass more rapidly than men, particularly around menopause.* "Age and bone mass" by Anatomy & Physiology, Connexions Web site is licensed under CC BY 3.0

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.

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13.2: 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)***.

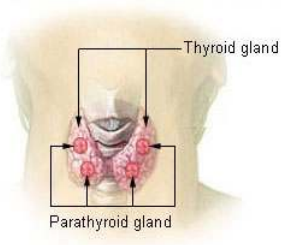


Figure 13.2.1: The thyroid and parathyroid glands are located at the back of the neck. "Thyroid and parathyroid glands" by National Cancer Institute is in the Public Domain

Let's take a closer look at how the body regulates blood calcium levels. If the blood calcium concentration drops too low, the parathyroid glands release ***parathyroid hormone***, or PTH. **PTH then acts in several ways to increase blood calcium levels**:

1. PTH stimulates the activity of osteoclasts to release calcium from bone.
2. PTH acts on the kidney to reduce the amount of calcium lost in the urine, returning more to circulation.
3. PTH stimulates enzymes in the kidney that convert vitamin D to its active form, also called ***calcitriol***. 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.

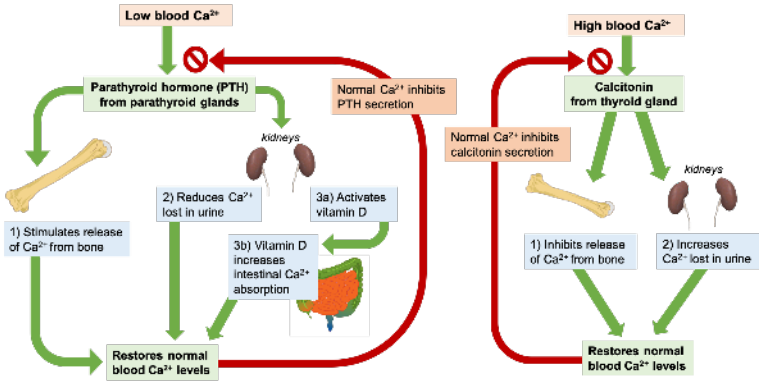


Figure 13.2.2: Blood calcium (Ca^{2+}) *levels are tightly regulated by PTH, vitamin D, and calcitonin.* "Calcium regulation" by Alice Callahan is licensed under CC BY 4.0, with kidney, bone, and intestine images by Mikael Haggstrom, in the Public Domain.

Through these two opposing pathways—PTH and vitamin D for raising blood calcium and calcitonin for lowering blood calcium—the body can very effectively maintain blood calcium homeostasis. This system 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.

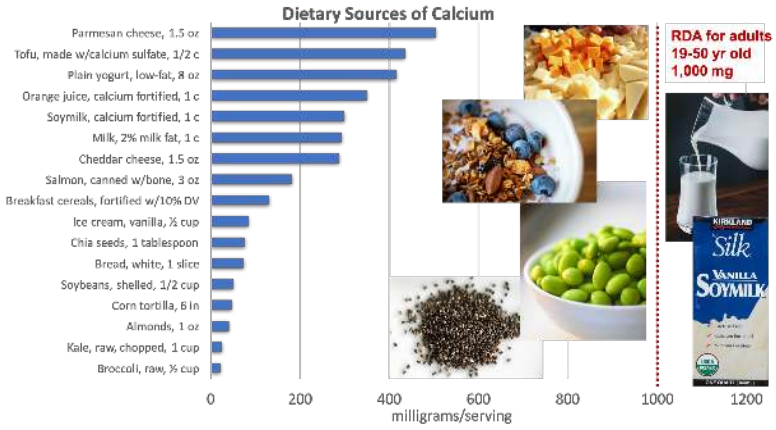


Figure 13.2.3: Dietary sources of calcium. *Examples of good sources pictured include cheese, milk, fortified soymilk, yogurt (with almond granola), edamame, and chia seeds. Source: NIH Office of Dietary Supplements and Dietary Guidelines for Americans, 2015-2020* . "Dietary sources of calcium" by Alice Callahan is licensed under CC BY 4.0, with images: "Cheese" by Finite Focus is licensed under CC BY-NC 2.0; milk photo by Eiliv-Sonas Aceron on Unsplash (license information); "yogurt and granola" by Marco Verch is licensed under CC BY 2.0; "edamame" by Carrie T is licensed under CC BY-NC 2.0; "soymilk" by Ian Fuller is licensed under CC BY-NC 2.0; and "chia seeds" by Stacy Spensley is licensed under CC BY 2.0.

Calcium bioavailability, or the amount of dietary calcium 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/boo...ion/index.html, CC BY-NC-SA 3.0

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- [1]National Institutes of Health Office of Dietary Supplements. (n.d.). *Calcium*. Retrieved April 23, 2020, from https://ods.od.nih.gov/factsheets/Calcium-HealthProfessional/

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13.3: Other Minerals Important to Bone Health

Phosphorus

Phosphorus is the second most abundant mineral in the human body, and 85% of the body's phosphorus is housed in the skeleton. In addition, phosphorus (in the form of phosphate) is a component of the backbones of RNA and DNA, adenosine triphosphate (ATP), and phospholipids. Phosphate also plays important roles in regulating cell signaling, enzyme activity, and acid-base balance, as well as being part of creatine phosphate, which is an energy source for muscles during exercise.[1]

Because phosphorus is present with calcium in mineralized bone, it is somewhat regulated in parallel to calcium. PTH and activated vitamin D stimulate bone resorption, increasing not only blood 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.

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.

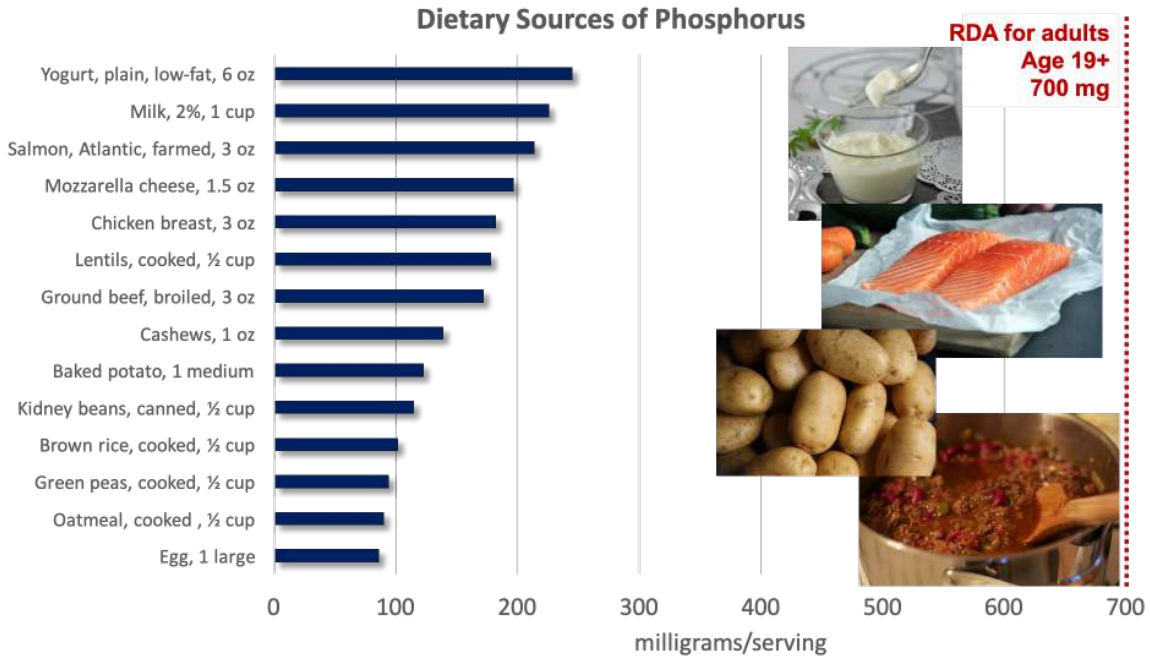


Figure 13.3.1: Food sources of phosphorus. Examples of good sources pictured include yogurt, salmon, potatoes, and chili (made with ground beef and kidney beans). Source: NIH *Office of Dietary Supplements* "Dietary sources of phosphorus" by Alice Callahan is licensed under CC BY 4.0, with images: Yogurt photo by Sara Cervera, salmon photo by Caroline Attwood, potato photo by Lars Blankers, all on Unsplash (license information); "Superbowl Chili" by Jake Przespo is licensed under CC BY 2.0

Phosphorus Deficiency and Toxicity

Both deficiency and toxicity of phosphorus are rare. The average 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]

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.

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.

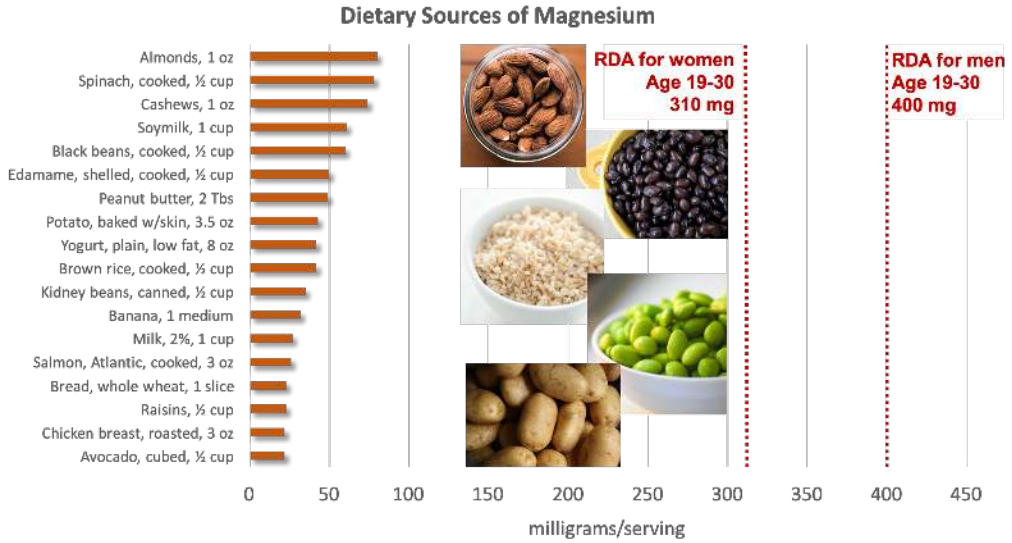


Figure 13.3.2: Dietary sources of magnesium. Examples of good sources pictured include almonds, black beans, brown rice, edamame, and potatoes. Source: *NIH Office of Dietary Supplements* "Dietary sources of magnesium" by Alice Callahan is licensed under CC BY 4.0, with images: Almond photo by Remi Yuan and potato photo by Lars Blankers, both on Unsplash (license information); "Black beans" by cookbookman17 is licensed under CC BY 2.0; "par cooked brown rice" by jules is licensed under CC BY 2.0; "edamame" by Carrie T is licensed under CC BY-NC 2.0

Magnesium Deficiency and Toxicity

Most people in the U.S. do not meet the RDA for magnesium, and studies indicate that consuming adequate magnesium may improve health. For example, people with higher dietary intakes of magnesium tend to have lower rates of cardiovascular disease, type 2 diabetes, and osteoporosis, leading some researchers to hypothesize that low intake of magnesium may increase the risk of these chronic diseases. 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]

Fluoride

Fluoride is a trace mineral needed in very small amounts in the body. It is known mostly as the mineral that combats tooth decay, but it also plays a role in assisting with tooth and bone development and maintenance. Because it isn't necessary for growth or to sustain life, fluoride is generally not considered an essential mineral. However, fluoride's role in preventing dental caries (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

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 13.3.3: Dietary sources of fluoride include water, tea, shellfish, and fluoridated dental products such as toothpaste. Dietary sources of fluoride, with water photo by manu schwendener, tea photo by Sarah Gualtieri, shrimp photo by AM FL, and toothpaste photo by William Warby, all on Unsplash (license information)

Fluoride Deficiency and Toxicity

Since 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 13.3.4: A mild case of fluorosis (left) vs. a severe case of fluorosis (right). "Dental fluorosis (mild)" by josconklin is licensed under CC BY 3.0 and "Dental fluorosis (excessive)" by Editmore is in the Public Domain

Because fluoridated oral care products often taste good, making them appealing to young children, it is important to 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.

Attributions

- Zimmerman, M., & Snow, B. Nutrients Important for Bone Health. In *An Introduction to Nutrition* (v. 1.0). https://2012books.lardbucket.org/boo...ion/index.html, CC BY-NC-SA 3.0
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13.4: Vitamin D- Important to Bone Health and Beyond

Vitamin D is unique among the vitamins because we can synthesize most of what we need in our skin. Sunlight is an essential ingredient in this process, so vitamin D is sometimes called the “sunshine vitamin.” However, the amount of vitamin D synthesized in the body is often not enough to meet our needs, so many people also need to consume dietary sources.

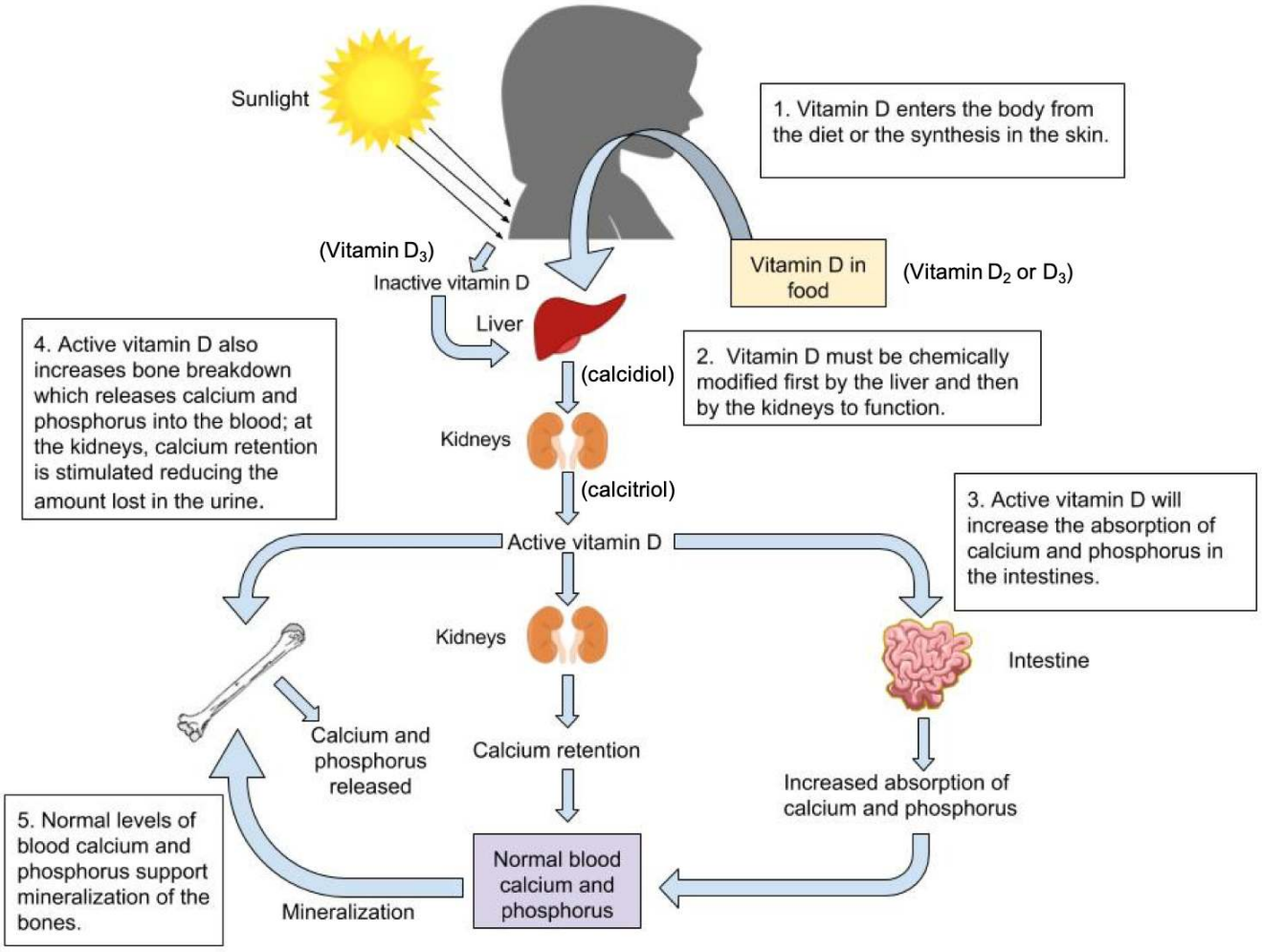
Metabolism and Functions of Vitamin D

Vitamin D synthesis in the skin begins with the conversion of cholesterol to 7-dehydrocholesterol. Then, in the presence of ultraviolet (UV) rays from sunlight, 7-dehydrocholesterol is converted to vitamin D_3 (also called ***cholecalciferol***), which is transported to the liver by a binding protein.

In dietary sources, vitamin D may be present in the form of vitamin D_3 from animal products or vitamin D_2 (also called ***ergocalciferol***), made by plants, mushrooms, and yeast. Dietary 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.

Recall from our discussion of regulation of blood calcium that one of the actions of parathyroid hormone (PTH) is to stimulate enzymes in the kidney that perform this last step in the activation of vitamin D. Active vitamin D increases the absorption of both calcium and phosphorus in the intestine, as well as working with PTH to reduce calcium loss in the urine and stimulate 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.



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Figure 13.4.1: Vitamin D can be synthesized in the skin (vitamin D_3) or provided in the diet (vitamin D_2 or D_3). It is converted by reactions occurring first in the liver (making calcidiol) and then kidney (making calcitriol, the active form). Once active, vitamin D works in several ways to ensure blood calcium homeostasis and enhance the availability of calcium for bone mineralization. "The Functions of Vitamin D" by Allison Calabrese is licensed under CC BY 4.0

Beyond its role in bone health, vitamin D has many other functions in the body. Cells throughout the body have vitamin D receptors in their nuclei, and by binding to these receptors, vitamin D is thought to regulate the expression of hundreds of genes. Specifically, vitamin D is known to play important roles in regulating cellular differentiation and growth, immunity, insulin secretion, and blood pressure. Studies have found *correlations* between low circulating vitamin D levels and increased risks of chronic diseases, including cancer, diabetes, cardiovascular disease, and multiple sclerosis. However, it has been difficult to determine if a lack of vitamin D actually contributes to the *cause* of these diseases, and research in this area is ongoing.[1]

Sunlight as a Source of Vitamin D

In most people, vitamin D synthesis in the skin provides a significant portion of their body's needs, and a little sun exposure can go a long way. Vitamin D researchers suggest that most people need between 5 and 30 minutes of sun exposure between 10 AM and 3 PM, at least twice per week, 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 may be needed to meet the vitamin D requirement.[2]

Dietary Sources of Vitamin D

Only a few foods are naturally good sources of vitamin D. These include fatty fish such as salmon, tuna, and mackerel, as well as 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]

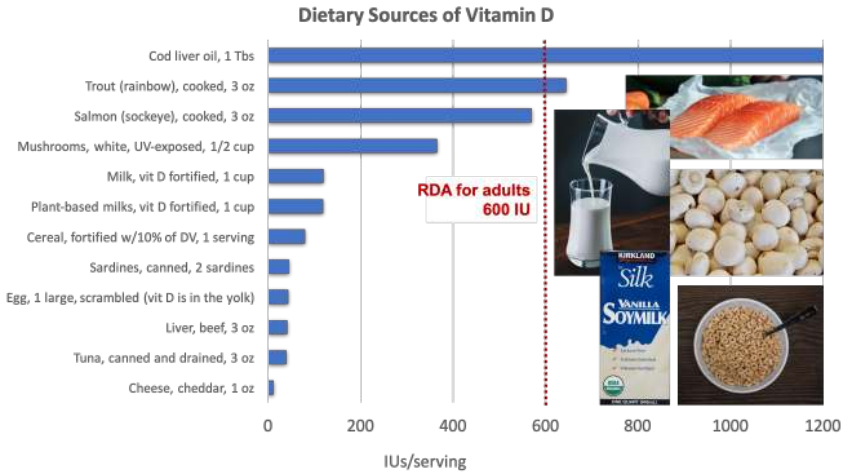


Figure 13.4.2: Dietary sources of vitamin D. Source: Examples of good sources pictured include salmon, milk, mushrooms, fortified soy milk, and fortified cereal. NIH *Office of Dietary Supplements*. Figure 9.12. "Dietary sources of vitamin D" by Alice Callahan is licensed under CC BY 4.0, with images: milk by Eiliv-Sonas Aceron on Unsplash (license information); salmon by Caroline Attwood on Unsplash (license information); white mushrooms by Waldemar Brandt on Unsplash (license information); soymilk by Ian Fuller is licensed under CC BY-NC 2.0; and cereal by John Matychuk on Unsplash (license information).

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 13.4.3: Vitamin D deficiency in children causes rickets, a disease in which inadequate vitamin D leads to soft, weak, and deformed bones. "Three children with rickets" by anonymous, Welcomme Collection is licensed under CC BY 4.0

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.

Attributions:

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CHAPTER OVERVIEW

14: Nutrients Important for Metabolism and Blood Health

14.1: Vitamins and Minerals Involved in Energy Metabolism

14.2: Vitamins and Minerals Involved in Blood Health

Template:HideTOC

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14.1: Vitamins and Minerals Involved in Energy Metabolism

Have you ever heard that taking vitamins will give you more energy? Or have you bought a product that claimed it could boost your energy level because it has added vitamins? Based on the knowledge that you've learned in this course, you know that vitamins are not broken down in the body to provide energy. So where does the idea that vitamins give you energy come from? On this page we will provide an overview of the B vitamins and several minerals that are important to the process of energy metabolism in the body, and take a closer look at two of those vitamins (folate and vitamin 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.

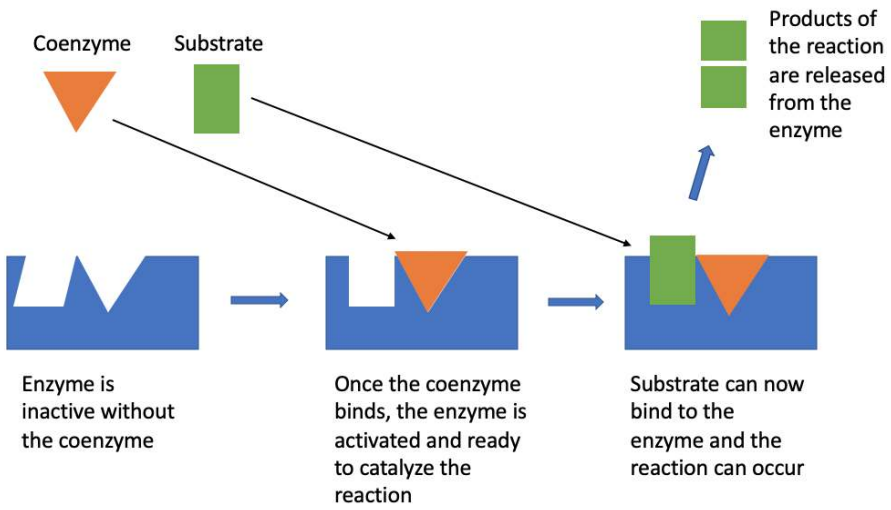


Figure 14.1.1: Role of a coenzyme assisting in an enzymatic reaction to break down a substrate. "Role of coenzyme" by Heather Leonard is licensed under CC BY 4.0

Vitamins that bind to enzymes are referred to as **coenzymes—***organic* molecules 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). The table below 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
Pyridoxine (B_6*)	Assists in the breakdown of glycogen and synthesis of amino acids, neurotransmitters, and hemoglobin
Biotin (B_7)	Assists in amino acid synthesis and glucose, fat, and protein metabolism,
Folate (B_9)	Assists in the synthesis of amino acids, RNA, DNA, and red blood cells
Cobalamin (B_{12}*)	Protects nerve cells and assists in fat and protein catabolism, folate function, and red blood cell synthesis
Minerals	**Role in Energy Metabolism**
Iodine	Assists in metabolism, growth, development, and synthesis of thyroid hormone
Manganese	Assists in carbohydrate and cholesterol metabolism, bone formation, and the synthesis of urea
Sulfur	A component in sulfur-containing amino acids necessary in certain enzymes; a component in thiamin and biotin
Chromium	Assists in carbohydrate, lipid, and protein metabolism, DNA and RNA synthesis
Molybdenum	Assists in metabolism of sulfur-containing amino acids and synthesis of DNA and RNA

*Normally used instead of common names

Table 14.1.1: Vitamins and minerals involved in energy metabolism and the role they each play. “Vitamins and minerals involved in energy metabolism” by Heather Leonard is licensed under CC BY 4.0

Do B Vitamins Give You Energy?

Because B vitamins play so many important roles in energy metabolism, it is common to see marketing claims that B vitamins boost energy and performance. This is a myth that is not backed by science. The “feeling” of more energy from energy-boosting supplements stems more from the high amount of added sugars, caffeine, and other herbal stimulants that accompany the high doses of B vitamins in these products. As discussed, B vitamins are needed to support energy metabolism and growth, but taking in more than required does not supply you with more energy. A great analogy of this phenomenon is the gas in your car. Does it drive faster with a half-tank of gas or a full one? It does not matter; the car drives just as fast as long as it has gas. Similarly, depletion of B vitamins will cause problems in energy metabolism, but having more than is required to run metabolism does not speed it up. And because B vitamins are water-soluble, they are not stored in the body and any excess will be excreted from the body, essentially flushing out the added expense of the supplements.

Deficiency and Toxicity

The B vitamins important for energy metabolism are naturally present in numerous foods, and many other foods are enriched with them; therefore, B vitamin deficiencies are rare. Similarly, most of the minerals involved in energy metabolism and listed above are trace minerals that are not frequently deficient in the diet. However, when a deficiency of one of these vitamins or minerals does occur, symptoms can be seen throughout the body because of their relationship to energy metabolism, which happens in all cells of the body. A lack of these vitamins and minerals typically impairs blood health and the conversion of macronutrients into usable

energy (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 nutrients are also uncommon, as excess intake is often excreted from the body. That doesn't mean taking high doses comes without risks. Large quantities, particularly through supplements, can lead to adverse side effects or cause interactions with medications. For example, too much niacin can cause 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).

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.

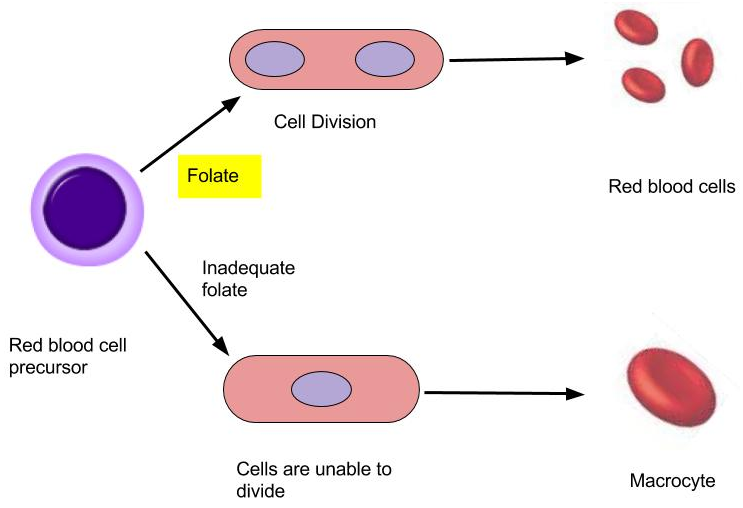


Figure 14.1.2: Folate and the formation of macrocytic anemia. Figure 9.15. "Folate and the formation of macrocytic anemia" by Allison Calabrese is licensed under CC BY 4.0

Folate is especially essential for the growth and specialization of cells of the central nervous system. Children whose mothers were folate-deficient during pregnancy have a higher risk of neural tube birth defects. Folate deficiency is causally linked to the development of ***spina bifida,*** a neural tube defect that occurs in a developing fetus when the spine does not completely enclose the spinal cord. Spina bifida can lead to many physical and mental disabilities. In 1998, the 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.

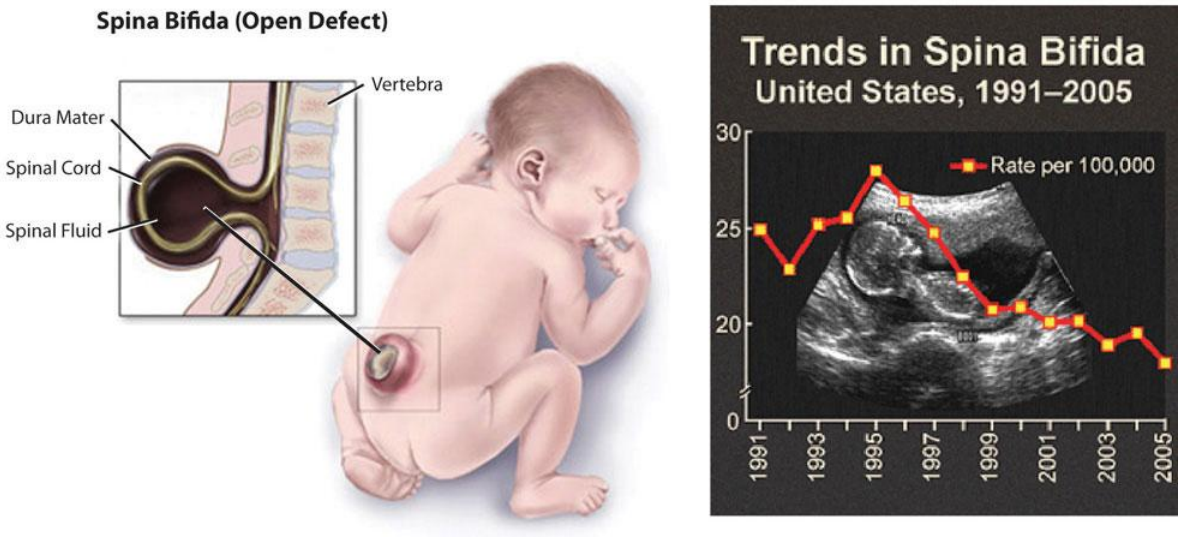


Figure 14.1.3: Spina bifida (left) is a neural tube defect that can have serious health consequences. The prevalence of cases of spina bifida has decreased significantly with the fortification of cereal and grain products in the United States beginning in 1998. Figure 9.16. "Spina bifida in infants" by Centers for Disease Control and Prevention is in the Public Domain

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.

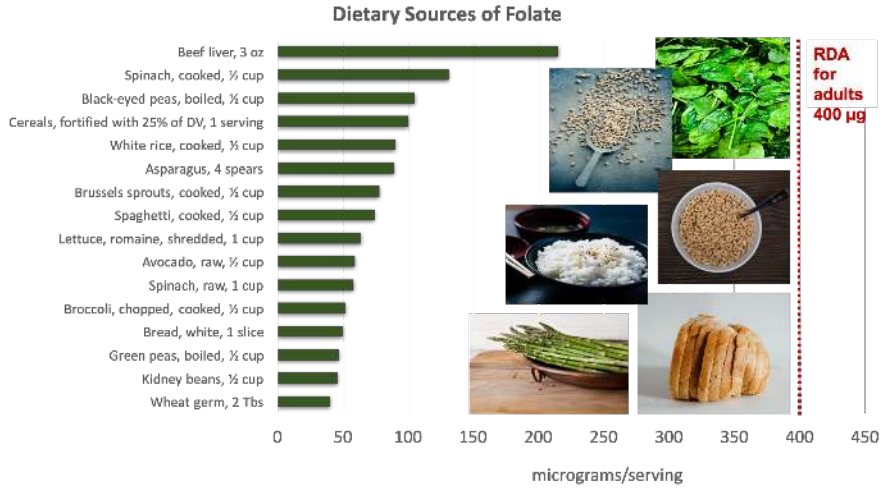


Figure 14.1.4: Dietary sources of folate. Examples of good sources pictured include spinach, black-eyed peas, fortified cereal, rice, and bread and asparagus. Source: NIH *Office of Dietary Supplements*. "Dietary sources of folate" by Alice Callahan is licensed under CC BY 4.0, with images: spinach by Nathan Nugent, black-eyed peas by Jasmine Waheed, breakfast cereal by John Matychuk, rice by Mgg Vitchakorn, asparagus by Stephanie Studer, and sliced bread by Stephanie Harvey, all on Unsplash (license information).

Folate Deficiency and Toxicity

Folate deficiency is typically due to an inadequate dietary intake; however, smoking and heavy, chronic alcohol intake can also decrease absorption, leading to a folate deficiency.[2] The primary sign of a folate deficiency is macrocytic anemia, characterized by large, abnormal red blood cells, which can lead to 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]

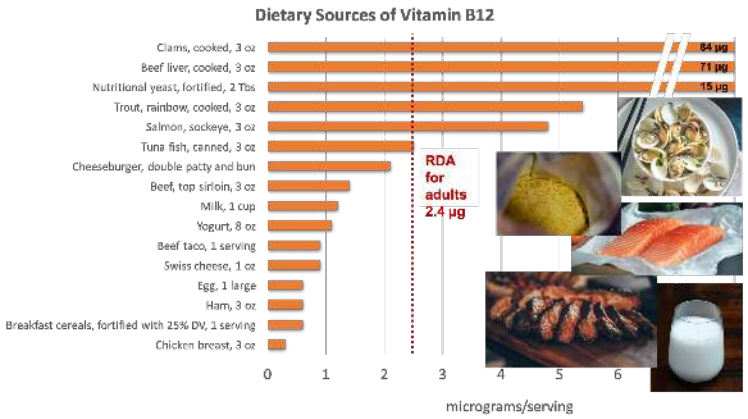


Figure 14.1.1: Dietary sources of vitamin B $_{12}$. *Examples of good sources pictured include clams, salmon, nutritional yeast, red meat, and milk. Source: NIH Office of Dietary Supplements , www.bragg.com*. "Dietary sources of vitamin B12" by Alice Callahan is licensed under CC BY 4.0, with images: Clams by Eiliv-Sonas Aceron, salmon filets by Caroline Attwood, sirloin by Emerson Vieira, glass of milk by Kim Gorga, all on Unsplash (license information); Nutritional yeast in bag by Tony Webster is licensed under CC BY 2.0.

Vitamin B12 Deficiency and Toxicity

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 primarily in foods of animal origin, 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]

Attributions:

- University of Hawai'i at Mānoa Food Science and Human Nutrition Program, "Human Nutrition," CC BY-NC 4.0
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14.2: Vitamins and Minerals Involved in Blood Health

Blood is essential to life. It transports absorbed nutrients and oxygen to cells, removes metabolic waste products for excretion, and carries molecules, such as hormones, to allow for communication between organs.

Blood is a connective tissue of the circulatory system, made up of four components forming a matrix:

- ***red blood cells*** (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 iron and vitamin K.

Iron

Iron is a trace mineral. It is a necessary component of many proteins in the body responsible for functions such as the transport of oxygen energy metabolism, immune function, and antioxidant defense. Iron is also important in brain development and function.

Iron is essential for oxygen transport because of its role in ***hemoglobin***, a protein in red blood cells that transports oxygen to cells and gives red blood cells their color. Hemoglobin is composed of four globular peptides, each with an iron-containing heme complex in the center.

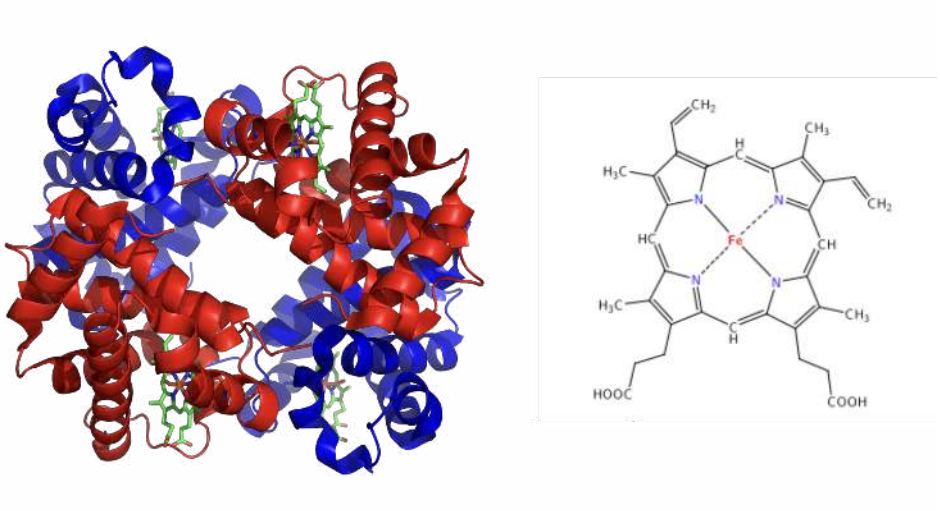


Figure 14.2.1: The structure of hemoglobin and the heme complex. On the left, the structure of hemoglobin includes four globular peptides (shown in blue and red) and the iron-containing heme groups (shown in green). On the right is a closer view of the heme complex. Figure 9.18. "Structure of Hemoglobin" by Zephyris at English Wikipedia is licensed under CC BY-SA 3.0 and "Heme" by Yikrazuul is in the Public Domain

The iron in hemoglobin is what binds to oxygen, allowing for transportation to cells. If iron levels are low, hemoglobin is not synthesized in sufficient amounts, and the oxygen-carrying capacity of red blood cells is reduced, resulting in ***anemia***. Iron is also an important part of ***myoglobin***, a protein similar to hemoglobin but found in muscles.

Dietary Sources of Iron

There are two types of iron found in foods:***heme iron*** and ***non-heme iron***.

- **Heme iron** is 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]

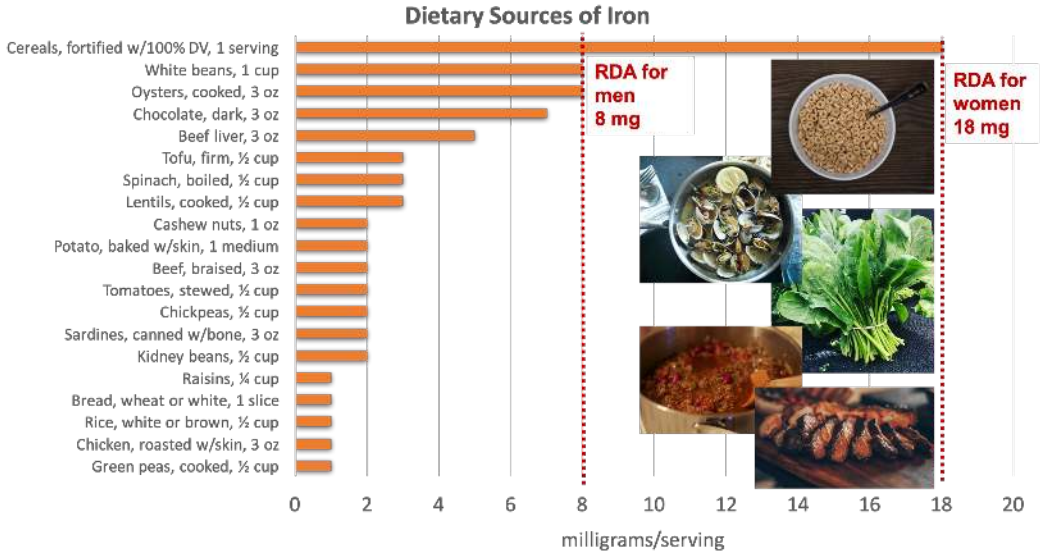


Figure 14.2.2: Dietary sources of iron. *Examples of good sources pictured include fortified cereal, clams, spinach, lentils and red meat. Source: NIH Office of Dietary Supplements*. "Dietary sources of iron" by Alice Callahan is licensed under CC BY 4.0, with images: Breakfast cereal by John Matychuk, 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.

The bioavailability of iron is approximately 14% to 18% from mixed diets and 5% to 12% from vegetarian diets.[2] Bioavailability is influenced by the dietary factors previously mentioned, as well as iron status. The body has no physiological mechanism to excrete iron; therefore, iron balance is tightly regulated by absorption.[2] When iron stores are low, more dietary iron will be absorbed.

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]

Iron Deficiency and Toxicity

Iron deficiency is one of the most common nutrient deficiencies, affecting more than a third of the world's population.[3]***Iron-deficiency anemia*** is a condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells that contain less hemoglobin. As a result, blood carries less oxygen from the lungs to cells. Iron-deficiency anemia has the following signs and symptoms, which are linked to the essential functions of iron in energy metabolism and blood health:

- Fatigue
- Weakness
- Pale skin
- Shortness of breath
- Dizziness
- Swollen, sore tongue
- Abnormal heart rate

Infants, children, adolescents, and women are the populations most at risk worldwide for iron-deficiency anemia.[4] Infants who are premature, 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.[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 14.2.1: A comparison of the RDAs for adult women of reproductive age, pregnancy, and adult men. "A comparison of the RDAs" by Tamberly Powell is licensed under CC BY 4.0 with data from National Institutes of Health of Dietary Supplements. *Iron – Health Professional Fact Sheet.* Retrieved April 29, 2020 from https://ods.od.nih.gov/factsheets/Iron-HealthProfessional/#en4

Additionally, those who frequently donate blood, as well as people with cancer, heart failure, or gastrointestinal diseases such as Crohn's, are at greater risk for iron inadequacy.[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).

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; therefore, the potential for toxicity from supplements is a concern. In children, death has occurred from ingesting as little as 200 mg of iron, so it is critical to keep iron supplements out of children's reach. The tolerable upper intake for iron is 45 mg per day for adults, based on the amount that causes gastrointestinal distress.[1]

Vitamin K

Vitamin K refers to a group of fat-soluble vitamins that are similar in chemical structure. They act as coenzymes and have long been known to play an essential role in blood ***coagulation*** or clotting. Vitamin K is also required for maintaining bone health, as it modifies a protein which is involved in the bone remodeling process.

Dietary Sources of Vitamin K

Vitamin K is found in the highest concentrations in green vegetables such as collard and turnip greens, kale, broccoli, and spinach. Soybean and canola oil are also common sources of vitamin K in the U.S. diet.[5] Additionally, vitamin K can be synthesized by bacteria in the large intestine, but the bioavailability of bacterial vitamin K is unclear.

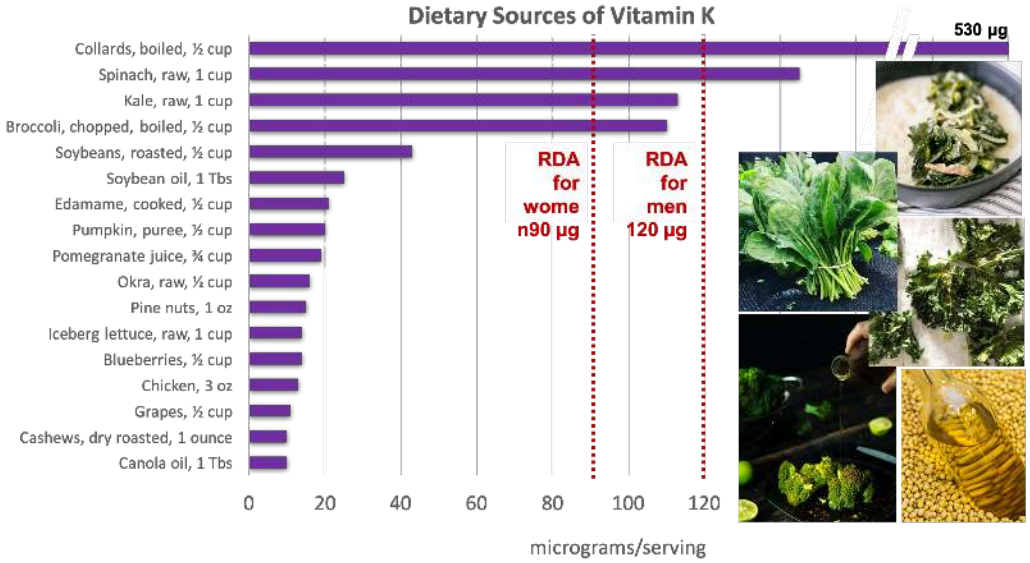


Figure 14.2.3: Dietary sources of vitamin K. *Examples of good sources pictured include chard, spinach, kale, broccoli, and soybean oil. Source: NIH Office of Dietary Supplements*. "Dietary sources of vitamin K" by Alice Callahan is licensed under CC BY 4.0, with images: Collards by Kim Daniels, spinach by Elianna Friedman, kale by Ronit Shaked, broccoli by Hessam Hojati, all on Unsplash (license information); "High oleic acid soybean oil_0030" by Mizzou CAFNR is licensed under CC BY-NC 2.0

Vitamin K Deficiency and Toxicity

Vitamin K deficiency is rare, as most U.S. diets are adequate in vitamin K.[5] A deficiency in vitamin K causes excessive bleeding (or ***hemorrhage)***. When there is damage to a blood vessel that results in bleeding, like a small tear, the body can stop this bleeding through a cascade of reactions. Without adequate vitamin K, blood does not clot properly, and this small bleed can turn into a larger problem, causing excessive bleeding or hemorrhage. People at risk are those who have malabsorption and other gastrointestinal disorders such as celiac disease. Newborns are also at risk for vitamin K deficiency during the first few months of life, as there is poor transfer of vitamin K across the placenta, and breastmilk is also low in vitamin K. Therefore, it has become a routine practice to inject newborns with a single intramuscular dose of vitamin K to prevent hemorrhaging, as bleeding within the skull is especially life-threatening.

The Food and Nutrition Board (FNB) has not established a UL for vitamin K because it has a low potential for toxicity.

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CHAPTER OVERVIEW

15: 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

15.1: Introduction to Nutrition and Physical Activity
15.2: Essential Elements and Benefits of Physical Fitness
15.3: Fuel Sources for Exercise
15.4: Nutrient Needs for Athletes

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15.1: 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 15.1.1: 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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15.2: Essential Elements and Benefits of Physical Fitness



Figure 15.2.1: Group exercise class photo by Anupam Mahapatra on Unsplash (license information)

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 promotes weight loss, strengthens muscles and bones, keeps the heart and lungs strong, and helps to protect against chronic disease. **There are four essential elements of physical fitness: cardiorespiratory endurance, muscular strength and endurance, flexibility, and maintaining a healthful body composition.** Each component offers specific health benefits, but optimal health requires some degree of balance between all four.

Some forms of exercise confer multiple benefits, which can help you to balance the different elements of physical fitness. For example, riding a bicycle for thirty minutes or more not only builds cardiorespiratory endurance, it also improves muscle strength and muscle endurance. Some forms of yoga can also build muscle strength and endurance, along with flexibility. However, meeting fitness standards in all four categories generally requires incorporating a range of activities into your regular routine. As you exercise regularly, your body will begin to change and you will notice that you are able to continue your activity longer and with greater ease.

The Essential Elements of Physical Fitness

Cardiorespiratory Endurance

Cardiorespiratory endurance is built by *aerobic training*, which involves activities that increase your heart rate and breathing such as walking, jogging, or biking. Aerobic exercise is continuous exercise (lasting more than 2 minutes) that can range from low to high levels of intensity. It increases heart and breathing rates to meet increased demands for oxygen in working muscles. Regular, moderate aerobic activity— about thirty minutes at a time for five days per week—trains the body to deliver oxygen more efficiently, which strengthens the heart and lungs and reduces the risk of cardiovascular disease. Strengthening your heart muscle and increasing the blood volume pumped each heartbeat boosts your ability to supply your body's cells with oxygen and nutrients, to remove carbon dioxide and metabolic wastes. It also leads to a lower resting heart rate for healthy individuals. In addition to the benefits of aerobic training for cardiovascular health, it is also an excellent way to maintain a healthy weight.

Muscle Strength

Muscle strength 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 high intensity training is used to build muscle strength with short, high-intensity activities. Building muscle strength and endurance is not just crucial for athletes and bodybuilders—it's important for children, seniors, and everyone in between. The support that your muscles provide allows you to work, play, and live more efficiently.



Figure 15.2.2: Weights photo by Kelly Sikkema on Unsplash (license information)

Strength training 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, and other exercises to build your muscles. If strength training is performed at least twice a week, it can help to improve muscle strength and to increase bone strength. It can help manage health conditions like diabetes, arthritis, dementia, hypertension, and many others. Strength training can also help you to maintain muscle mass during a weight-loss program.[1]

Flexibility

Flexibility is the range of motion available to your joints. Yoga, tai chi, Pilates, and stretching exercises work to improve this element of fitness. Stretching not only improves your range of motion, it also promotes better posture, and helps you perform activities that can require greater flexibility, such as chores around the house. In addition to working on flexibility, older adults should include balance exercises in their regular routine. Balance tends to deteriorate with age, which can result in falls and fractures.[2]

Body Composition

Body composition is the proportion of fat and fat-free mass (which includes bones, muscles, and organs) in your body. A healthy and physically fit individual has a greater proportion of muscle and smaller proportion of fat than an unfit individual of the same weight. Although habitual physical activity can promote a more healthful body composition, other factors like age, gender, genetics, and diet contribute to an individual's body composition. You can refer back to a previous chapter for a detailed discussion on body composition, how it is measured, and how it is used as an indicator for health.

The Benefits of Physical Activity

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. You can review the guidelines here, including recommendations for children, adolescents, and adults.[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 an exercise program on a regular basis. If you are nervous or unsure about becoming more active, the good news is that moderate-intensity activities, such as brisk walking, are safe for most people. Also, the health advantages of becoming active far outweigh the risks. Physical activity not only helps to maintain your weight, it also provides a wealth of benefits—physical, mental, and emotional.

Physical Benefits	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, can 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.
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.	

Table 15.2.1: Physical and emotional benefits of exercise. "Physical and emotional benefits of exercise" by Heather Leonard is licensed under CC BY-NC-SA 2.0

The FITT Principle

One helpful tool for putting together an exercise plan is the FITT acronym. 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 has flexibility and works with your lifestyle. By changing up the types of exercise you do, varying the intensity of your workouts, and by 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 to outline the components of the FITT principle to establish more detailed goals and create purpose for your workouts.

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- University of Hawai‘i at Mānoa Food Science and Human Nutrition Program. (2018). Performance Nutrition. *Human Nutrition*. pressbooks.oer.hawaii.edu/humannutrition/chapter/introduction-11/

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15.3: 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. 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.

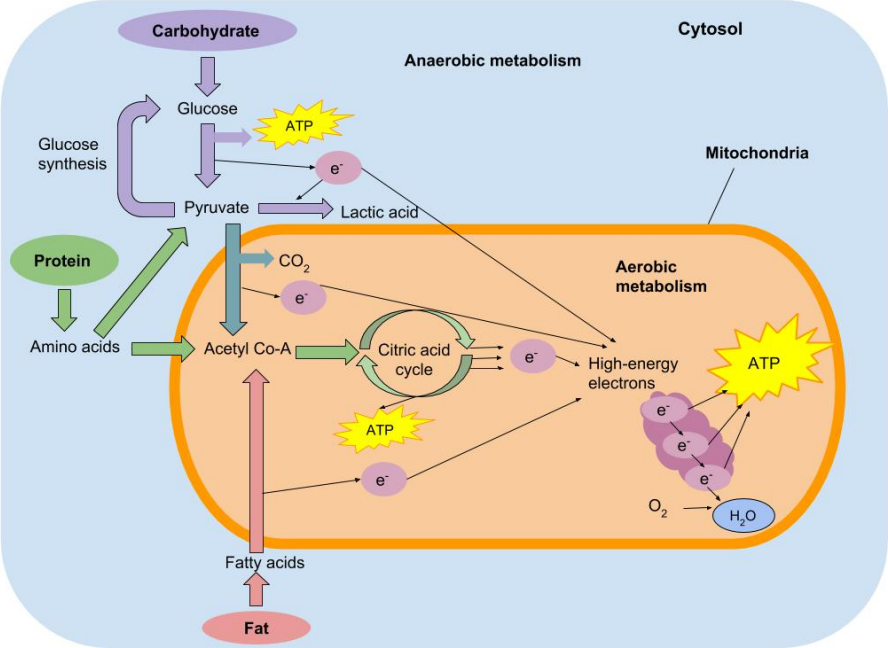


Figure 15.3.1: Anaerobic vs aerobic metabolism. Note that carbohydrate is the only fuel utilized in anaerobic metabolism, but all three macronutrients can be used for fuel during aerobic metabolism. "Anaerobic vs Aerobic Metabolism" by Allison Calabrese is licensed under CC BY 4.0

Physical Activity Duration and Fuel Use

The respiratory system plays a vital role in the uptake and delivery of oxygen to muscle cells throughout the body. Oxygen is inhaled by the lungs and transferred from the lungs to the blood, where the cardiovascular system circulates the oxygen-rich blood to the muscles. The oxygen is then taken up by the muscles and can be used to generate ATP. When the body is at rest, the heart and lungs are able to supply the muscles with adequate amounts of oxygen to meet the 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.

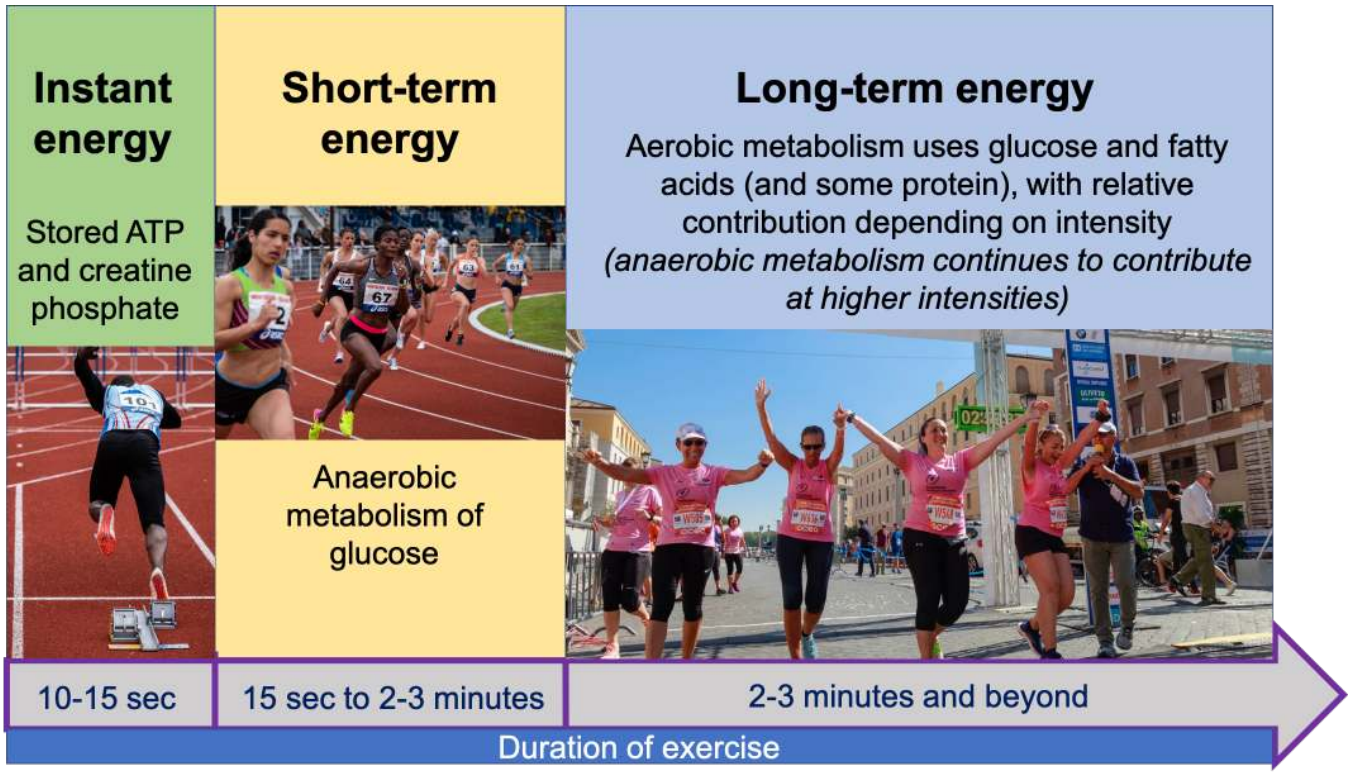


Figure 15.3.2: Energy systems used to fuel exercise change with duration of exercise. The ATP-creatine phosphate system is used up within seconds. The short-term and long-term systems kick in and provide energy for exercise as the duration of the workout goes on. "Energy systems used to fuel exercise change with duration of exercise" by Alice Callahan is licensed under CC BY 4.0, with images: Instant energy sprint photo and short-term energy women on track photos by Nicolas Hoizey; long-term energy race finish photo by Peter Boccia, all on Unsplash (license information)

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.

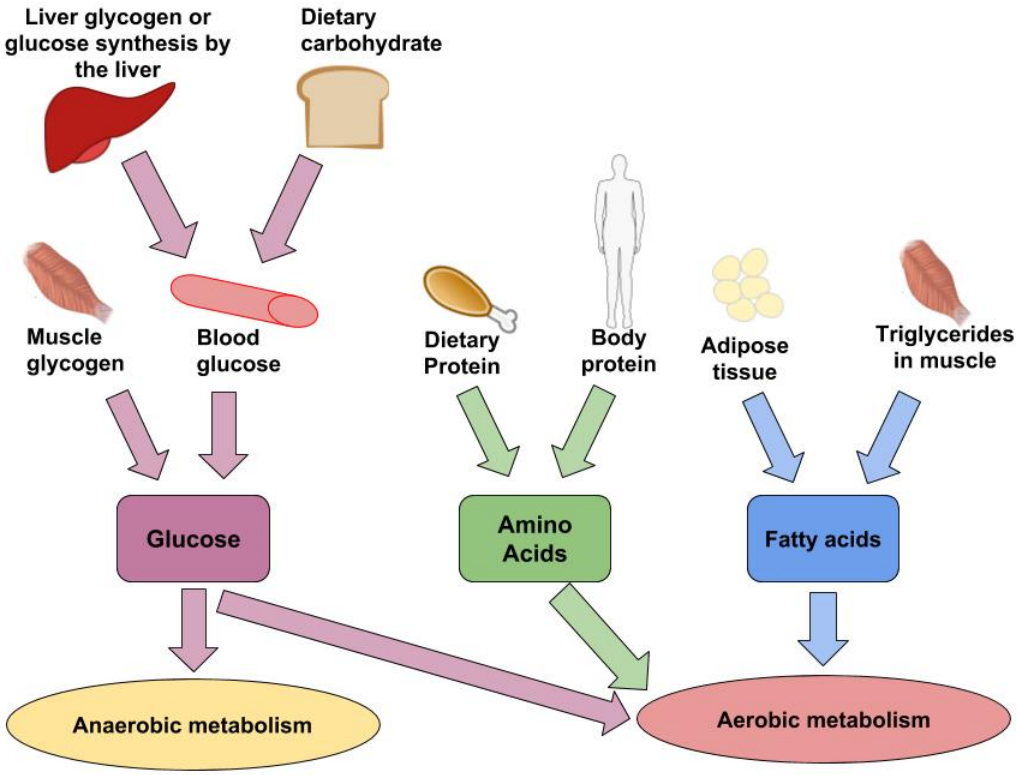


Figure 15.3.3: Fuel sources for anaerobic and aerobic metabolism. Both dietary sources and body storage of carbohydrates, fat, and protein can all be used to fuel activity. Amount varies depending on duration and intensity of the activity. "Fuel Sources for Anaerobic and Aerobic Metabolism" by Allison Calabrese is licensed under CC BY 4.0

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.

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

Table 15.3.1: Summary of fuels used for activities of different intensities and durations. "Summary of Fuels" by Tamberly Powell is licensed under CC BY-NC-SA 2.0

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.

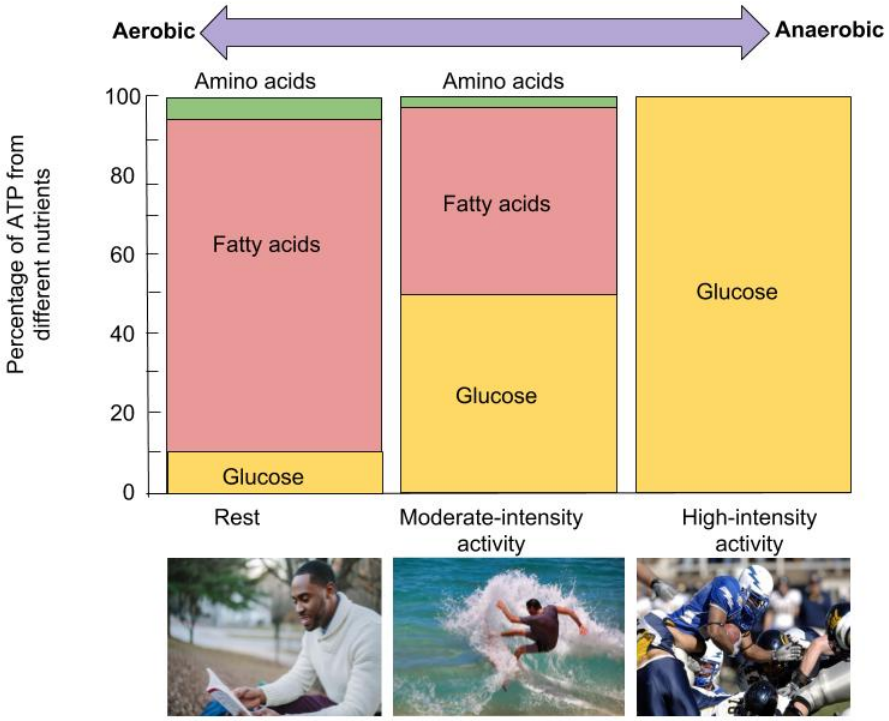


Figure 15.3.4: The effect of exercise intensity on fuel sources. Anaerobic exercise utilizes only glucose for fuel. As activities become more aerobic, the body can utilize fatty acids and, to a small extent, amino acids, for energy production. "The Effect of Exercise Intensity on Fuel Sources" by Allison Calabrese is licensed under CC BY 4.0

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.

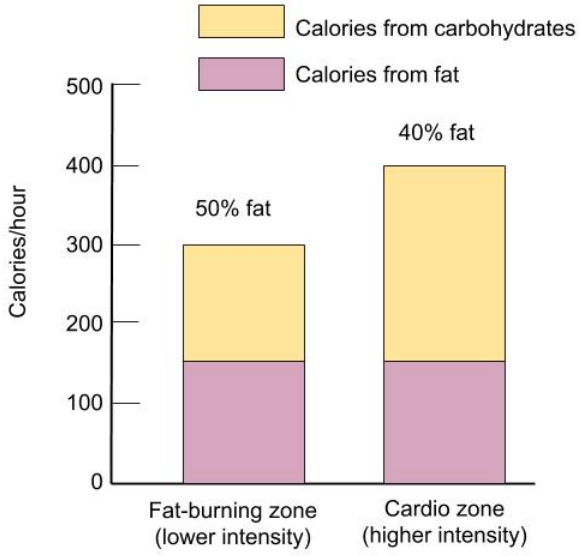


Figure 15.3.5: The fat-burning zone. While a greater percentage of calories burned in lower intensity exercise come from fat, the overall total calorie burn is greater in higher intensity exercise. "The Fat-burning Zone" by Allison Calabrese is licensed under CC BY 4.0

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- University of Hawai'i at Mānoa Food Science and Human Nutrition Program. (2018). Performance Nutrition. *Human Nutrition*. pressbooks.oer.hawaii.edu/humannutrition/chapter/introduction-11/

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15.4: 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.



Figure 15.4.1: Training table photo by Shayda Torabi on Unsplash (license information)

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.[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

Table 15.4.1: Athlete's daily needs for carbohydrate fuel[1] "Athlete's daily needs for carbohydrate" by Heather Leonard is licensed under CC BY-NC-SA 2.0

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)



Figure 15.4.2: Parfait photo by amirali mirhashemian on Unsplash (license information)

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.

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.

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. It is important to continue to consume water before, during, and after exercise to avoid dehydration as much as possible.

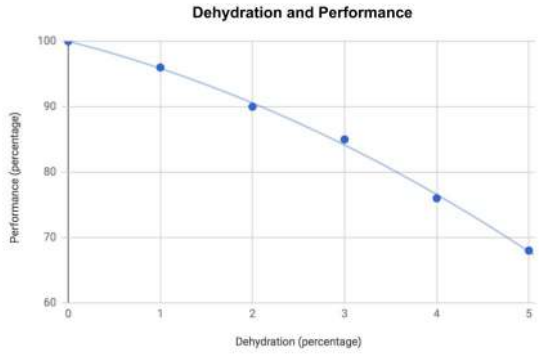


Figure 15.4.3: The effect of dehydration on exercise performance. “Dehydration’s Effect on Exercise Performance” by Allison Calabrese is licensed under CC BY 4.0

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.

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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Figure 15.4.4: Drinking water photo by Damir Spanic on Unsplash (license information)

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.

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CHAPTER OVERVIEW

16: Nutrition For A Healthy Life



Figure 16.1: Photo by Jannis Brandt / Unsplash License

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16.2: Behavior Change- The Transtheoretical Model
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16.1: Chronic Diseases

Learning Objectives

- Discuss the roles of nutrition and lifestyle choices in the prevention and management of chronic disease.

Chronic Diseases

Chronic diseases are ongoing, life-threatening, and life-altering health challenges. They are the leading cause of death worldwide. Chronic conditions are increasing in frequency. They cause significant physical and emotional suffering and are an impediment to economic growth and vitality. It is important, now more than ever, to understand the different risk factors for chronic disease and to learn how to prevent their development.

The Risk Factors of Chronic Disease

A **risk factor** is a signal that your chances for acquiring a chronic disease may be increased. You might liken a risk factor to the flags that lifeguards sometimes set up at beaches. When you see these flags, you know immediately that swimming within the marked areas could be hazardous, and that if you choose to swim within these parameters anyway, you are doing so at your own risk. But, if you heed the warnings, you are taking the necessary step to protect your safety and health. Similarly, risk factors are warning signs that coincide with the development and progression of disease. However, risk factors are not a 100-percent guarantee that a person will develop a chronic disease, only that the conditions are right. For example, if a person gets sick with the flu, we can say with certainty that the illness was caused by a virus. However, we cannot say that a sedentary lifestyle caused the onset of cardiovascular disease in a patient, because a risk factor indicates a correlation, not a causation.

Chronic disease usually develops alongside a combination of the following risk factors: genetics, another health factor such as obesity or hypertension, dietary and lifestyle choices, and environmental problems. Risk factors such as genetics and age cannot be changed. However, some risk factors can be altered to promote health and wellness (such as diet). For example, a person who continuously eats a diet high in sugars, saturated fats, and red meat is at risk for developing Type 2 diabetes, cardiovascular disease, or several other conditions. Making more healthy dietary choices can greatly reduce that risk. Being a woman over age sixty-five is a risk factor for developing osteoporosis, but that cannot be changed. Also, people without a genetic predisposition for a particular chronic illness can still develop it. Not having a genetic predisposition for a chronic disease is not a guarantee of immunity.

Identifying Your Risk Factors

To estimate your own risk factors for developing certain chronic diseases, search through your family's medical history. What diseases do you note showing up among close blood relatives? This may be of concern to you. At your next physical, pay attention to your blood tests and ask the doctor if any results are out of the normal range. It is also helpful to note your vital signs, particularly your blood pressure and resting heart rate. In addition, you may wish to keep a food & mood diary to make a note of the dietary choices that you make on a regular basis and be aware of what your eating patterns are. As a general rule, it is important to look for risk factors that you can modify.to promote your health. For example, if you discover that your grandmother, aunt, and uncle all suffered from high blood pressure, then you may decide to avoid a high sodium diet. Identifying your risk factors can arm you with the information you need to help ward off disease.

Cardiovascular Disease

Throughout the remainder of this section, we will examine some of the more prevalent chronic diseases, their risk factors, and the choices that can help to discourage their development or progression. Let's begin with cardiovascular disease. According to the Centers for Disease Control and Prevention (CDC), heart disease is the leading cause of death in the United States (1).

The disease generally starts with atherosclerosis, or a hardening of the arteries, a chronic condition so common that most people show signs of it by the time they turn thirty. Arteries start to narrow and harden when fats accumulate along their inner walls and form plaques. A plaque is made of fat, cholesterol, calcium, and other substances found in blood.

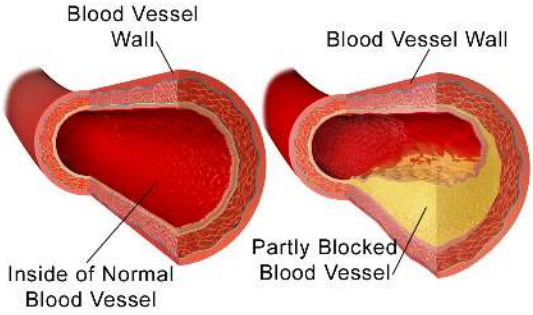


Figure 16.1.2: Illustration comparing a normal blood vessel and partially blocked vessel due to atherosclerotic plaque build-up. Plaque formation along arterial walls impedes blood flow and can create a thrombus, or stationary blood clot. from BruceBlaus (via Wikipedia). For a video of the process click here.

Plaque formation causes arteries to narrow and harden, which elevates blood pressure because the vessels can't expand effectively to accommodate blood pulses. Higher blood pressure strains the heart and causes more damage. Arterial walls can become so weakened due to high blood pressure that they balloon and form what is known as an aneurysm. If the aneurysm bursts, it becomes a life-threatening event. The plaques themselves can also rupture due to a spike in blood pressure or a tremor along an arterial wall, and the body responds to this perceived injury by forming blood clots. These clots are serious health threats, whether they are stationary (a thrombus) or moving (an embolus). A stable clot can slowly kill off surrounding tissue, or grow so big that it blocks blood circulation and causes thrombosis. When a moving clot becomes stuck in an artery too small for its passage, it cuts off blood flow and causes cell death. This is referred to as an embolism. Blood clots in heart and brain arteries can cause heart attacks or strokes.

Table 16.1.1: The Risk Factors for Cardiovascular Disease

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** Risk increases for men at forty-five, and for women at fifty-five. • **Sex.** Men have a higher risk than women, though the risk for women steeply rises after menopause. • **Family history.** The more family members who have heart disease, the greater the risk.	• **Cigarette smoking.** Nicotine constricts blood vessels, and carbon monoxide damages their inner lining, which increases the risk of atherosclerosis. • **Excess body fat.** This worsens other risk factors. • **Diabetes.** This condition is associated with an increased risk of heart disease. Both types have certain risk factors in common, including obesity and high blood pressure. • **Physical activity.** Lack of exercise is associated with heart disease, too much exercise is associated with relative energy deficiency, and osteopenia. • **Cholesterol levels.** High levels of blood cholesterol can increase the risk. A high level of low-density lipoprotein (LDL), or the "bad" cholesterol, is a common contributing factor. However, a low level of high-density lipoprotein (HDL), or "good" cholesterol, can also promote atherosclerosis.

Steps to Reducing the Risk of Cardiovascular Disease

Diet and nutrition can play a significant role in reducing the risk of cardiovascular disease. It is helpful to lower sodium intake, increase consumption of dietary fiber, and limit consumption of saturated fat, which promotes plaque formation. In addition, it is important to replace refined starches and added sugar, which can boost triglycerides, with whole grains, fruits, and vegetables. Eating foods rich in omega-3 fatty acids, especially fish, using alcohol in moderation, and opting for low or no-fat dairy products can all help reduce your cardiovascular disease risk. Emphasizing vegetable-based sources of protein, such as beans and legumes, can be beneficial, as well as consuming more soy products. It is also important to maintain a healthy weight, manage cholesterol levels, and avoid smoking or chewing tobacco.

Hypertension

Chronic high blood pressure, also known as hypertension, is a significant health hazard affecting one out of three adults in the United States(2). This chronic condition is a major cause of heart attacks and strokes, yet it has no symptoms until blood pressure reaches very high levels, which is why it is known as “the silent killer.” The only way to find out if you have high blood pressure is to get an accurate reading of your resting blood pressure rate, which is best done by a medical professional and should be monitored regularly.

High blood pressure is such an important factor in cardiovascular disease, that keeping it within a healthy range is vitally important. Blood pressure readings consist of two numbers. The top number measures **systolic** pressure (when the heart contracts) and the bottom number measures **diastolic** pressure (when the heart is at rest). The key blood pressure numbers to keep in mind are:

- **Ideal.** below 120 over 80
- **Pre-hypertension.** 120-129 over 80
- **Hypertension.** Stage 1: 130 - 139 or 80-89, Stage 2: over 140 or over 90

Table 16.1.2: The Risk Factors for Hypertension

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** After fifty-five, the risk of developing high blood pressure is 90 percent. • **Race.** African-Americans are more likely to develop hypertension, manifest it at a younger age, and have higher blood pressure readings. • **Family history.** There is a strong genetic component to high blood pressure, and an individual’s risk goes up along with the number of family members who have hypertension.	• **Excess body fat.** Roughly 60 percent of people with hypertension are obese. • **Sodium consumption.** The more salt in a person’s diet, the more likely they are to have high blood pressure. • **Alcohol.** Drinking more than two drinks per day for men and one drink for women increases the likelihood of hypertension. • **Diet.** In addition to salt and alcohol consumption, other dietary factors increase chances of developing hypertension. • **Sleep**. Not getting enough sleep on a regular basis is linked to an increased risk of heart disease, high blood pressure, and stroke.(3)

Steps to Reducing the Risk of High Blood Pressure

Although it is not possible to change one’s age or genetics, there are actions that people can take to decrease their risk of hypertension. Techniques to reduce blood pressure include becoming physically active, maintaining a healthy weight, reducing sodium intake below 2,400 milligrams per day (or below 1,500 milligrams if you are in a high-risk group or already have been diagnosed with hypertension), using alcohol moderately, and following the DASH diet. Additionally, vitamin C, calcium, and potassium have all been shown to promote healthy blood pressure. It is also vital to monitor your blood pressure levels on a regular basis. Prompt intervention when readings rise above the ideal level (120 over 80) can save lives, which is why everyone should know the status of their blood pressure.

Cancer

More than one hundred diseases are classified as different forms of cancer, all of them characterized by the uncontrolled growth of abnormal cells. Cancer is triggered by mutations in a cell’s genetic material. The cause of these changes may be inherited, or it may result from exposure to carcinogens, which are agents that can cause cancer. Carcinogens include chemicals, viruses, certain medical treatments such as radiation, pollution, or other substances and exposures that are known or suspected to cause cancer(4). The National Institutes of Health has classified fifty-four different compounds as known cancer-causing agents in humans (5).

Under normal conditions, a healthy cell will either repair any damage that has been done or self destruct so that no future cells will be affected. Cells become cancerous when their DNA is damaged, but they do not self-destruct or stop reproducing as normal cells would. As these abnormal cells continue their rapid growth, in most cancers they coalesce in a mass called a tumor. Cancer cells can overwhelm healthy cells and interfere with the healthy functioning of the body. They can also invade other organs and spread throughout the body in a process known as metastasis. Scientists and the medical community are giving considerable attention to the early stages of cancer, from the moment a healthy cell is exposed to a carcinogen to the point where cells with damaged DNA are replicating out of control. Intervention at any of these early stages could prove to be quite beneficial because it is thought that most cancers are the result of lifestyle choices and environmental exposure.

The risk factors for different cancers can vary. For example, exposure to ultraviolet radiation from the sun and from tanning beds is a risk factor for skin cancer, while exposure to asbestos is a risk factor for mesothelioma cancer. Table 16.1.3 shows some common risk factors for a number of different types of cancer.

Table 16.1.3: The Risk Factors for Cancer

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** Most cancers occur in people over the age of sixty-five. However, people of all ages, including children, can get cancer. • **Family history.** Certain types of cancer have a genetic link. However, environmental factors may also play a part.	• **Tobacco.** Smoking or chewing tobacco greatly increases the risk for certain cancers, including cancer of the lungs, bladder, cervix, kidneys, mouth, and pancreas. • **Alcohol.** Drinking alcohol is linked to cancers of the mouth, throat, esophagus, and breast, as well as to cancers of the neck and head. • **Excess body fat.** Linked to cancers of the colon, uterus, pancreas, esophagus, kidney, and breast. • **Cooking techniques.** Grilling, smoking, and preparing meat at high temperatures forms carcinogens. • **Red meat.** The risk of colon cancer seems to increase with the consumption of red meat and processed meat. • **Cured meats.** According to a recent study, there is a mild risk of pancreatic cancer with the consumption of cured meats, such as sausage, pepperoni, bacon, ham, smoked turkey, salami, and hot dogs. • **Physical inactivity.** Linked to colon, breast, and other cancers. • **Exposure to chemicals.** People who have jobs that expose them to chemicals on a regular basis, such as construction workers and painters, have an increased risk of cancer. • **Viruses or bacteria.** Certain viruses or bacteria may increase the risk of developing cancer. For example, human papillomaviruses, which are sexually transmitted, are the primary cause of cervical cancer.

Steps to Reducing the Risk of Cancer

According to the American Cancer Society, half of all American men and one-third of American women will be diagnosed with some form of cancer in their lifetime (6). Although cancer is one of the leading causes of death worldwide, ongoing research and innovations in treatment have improved the outlook for cancer patients to the point where millions now survive or live with cancer, making it a chronic disease.

The American Institute for Cancer Research (AICR) has published guidelines for preventing cancer and staying healthy. They include several dietary and lifestyle choices, such as participating in physical activity for thirty minutes per day or more, and maintaining a healthy weight. In addition, AICR recommends consuming a plant-based diet (7). Several epidemiological studies have found a link between eating plenty of fruits and vegetables and a low incidence of certain cancers. Fruits and vegetables containing a wide variety of nutrients and phytochemicals may either prevent or reduce oxidative damage to cell structures. Cruciferous vegetables, such as cauliflower, broccoli, and Brussels sprouts, may also reduce the risk of certain cancers, such as endometrial, esophageal, and others. Also, studies have shown that the more fiber you have in your diet, the lower your risk of colon cancer.

Supplementation may also be helpful to a limited degree. Vitamin D and antioxidants have been linked to lowering the risk of some cancers (however taking an iron supplement may promote others); but, obtaining vital nutrients from **food first** is the best way to help prevent or manage cancer. In addition, regular and vigorous exercise can lower the risk of breast and colon cancers, among others. Also, wear sunblock, stay in the shade, and avoid the midday sun to protect yourself from skin cancer, which is one of the most common kinds of cancer (8).

Diabetes

The World Health Organization reports that more than 346 million people around the world have diabetes and they predict that deaths due to the consequences of diabetes will double from 2005 to 2030 (9). **Diabetes mellitus** is a metabolic disorder that results when the pancreas does not produce enough insulin to meet its needs or the body does not effectively utilize the insulin that it does produce. Insulin is the hormone that regulates blood glucose levels. The most common complication is hyperglycemia (elevated blood sugar), which gradually leads to damage in many of the body's systems, most notably the eyes, kidneys, nerves, and heart and blood vessels.

There are three kinds of diabetes: Type 1, Type 2, and gestational. Formerly known as juvenile or childhood-onset diabetes, Type 1 diabetes is an autoimmune condition in which the pancreas does not produce insulin. Type 1 diabetes is not preventable, and its cause is unknown. Symptoms include excessive urination, thirst, persistent hunger, weight loss, vision problems, and fatigue.

Formerly known as adult-onset diabetes, Type 2 diabetes results when the pancreas produces enough insulin initially, but the body is unable to use the hormone properly (insulin resistance). Until recently, this disease was only found in adults. However, it is now found among children, too. More than 90 percent of diabetics have Type 2 (10). Major contributing factors to the development of Type 2 diabetes include excessive body weight and physical inactivity. The symptoms for Type 2 diabetes are similar to Type 1, but are much less noticeable. As a result, Type 2 diabetes may remain undiagnosed for several years after the onset, generally after complications have already manifested.

About 3 to 8 percent of pregnant women develop gestational diabetes during the latter stages of pregnancy. This condition is caused by a shortage of insulin or by pregnancy hormones. Gestational diabetes has symptoms similar to Type 2 diabetes, and some women may not experience any symptoms at all. In general, gestational diabetes fades away after the birth of the baby. However, women who have had gestational diabetes are at a greater risk of developing Type 2 diabetes within five to ten years. Also, infants born of mothers who suffer from this condition are at an increased risk of developing Type 2 diabetes as they grow older (11).

Table 16.1.4: The Risk Factors for Diabetes

Unmodifiable Risk Factors	Modifiable Risk Factors
• **Age.** Risk increases after age forty-five • **Medical history.** Diabetes during a previous pregnancy or recently giving birth to an infant who weighs more than 9 pounds. • **Family history.** A history of diabetes among one or more close relatives. • **Race and ethnicity.** Individuals from specific ethnic groups may have an increased risk for developing diabetes, including African Americans, Hispanic Americans, Asian Americans, and Native Americans. • **Viruses.** Exposure to: Epstein-Barr, Coxsackie, mumps, or cytomegalo viruses may trigger Type 1 diabetes.	• **Cigarette smoking.** Nicotine constricts blood vessels, and carbon monoxide damages their inner lining, which increases the risk of Type 2 diabetes. • **Excess body fat.** Excess body fat, especially around the waist, is a major contributing factor to Type 2 diabetes. • **Physical inactivity.** Lack of exercise is strongly associated with diabetes. • **High blood pressure.** Greater than or equal to 140/90 mmHg. • **Cholesterol levels.** HDL cholesterol under 35 mg/dL. • **Blood sugar.** Impaired glucose tolerance. • **Blood fats.** Elevated triglycerides (250 mg/dL or more).

Steps to Reducing the Risk of Diabetes

Unfortunately, Type 1 diabetes is almost impossible to prevent, although some clinical research suggests that breastfeeding an infant for at least three months may decrease the child's risk of developing this condition. However, people who are at risk for Type 2 or gestational diabetes can take steps to avoid the disease. For example, it is crucial to achieve and maintain a healthy body through regular physical activity. If you are at risk, strive for at least thirty minutes of moderate to intense exercise at least three times per week. Proper nutrition is also vital, and it is important to restrict sugary snacks, beverages, and desserts, and to limit the intake of trans fats and saturated fats. In addition, those who are at risk should consume whole grains, legumes, fruits, and vegetables, along with two servings of non-fried fish per week.

For people over age forty-five, it is important to have a glucose test every three years. Regular testing should begin at a younger age, and be performed frequently if you have any risk factors for developing Type 2 diabetes. In order to assess your health status, the following is recommended:

- Early diagnosis through blood testing
- Blood pressure measurement

- Blood lipid measurement

Food: The Best Medicine

Poor dietary choices and a sedentary lifestyle account for about 300–600 thousand deaths every year according to the US Department of Health and Human Services. That number is thirteen times higher than the deaths due to gun violence (12). The typical North American diet is too high in saturated fat, sodium, and sugar, and too low in fiber in the form of whole fruits, vegetables, and whole grains to keep people healthy. With so many threats to optimal health, it is vital to address those factors that are under your control, namely dietary and lifestyle choices. A diet that supplies your body with the needed energy and nutrients daily will result in efficient body functioning and in protection from disease. Making sound nutritional choices can also provide support for individuals undergoing treatment for short-term or chronic conditions. Finding a balance between nutritional needs with concerns about drug interactions can hasten recovery, improve quality of life, and minimize the side effects from treatment protocols.

Key Takeaways

Chronic diseases such as cardiovascular disease, high blood pressure, cancer, and diabetes are major public health threats and major causes of mortality. Knowing the modifiable risk factors (such as diet, level of physical activity, and cigarette smoking) for certain diseases can help you to adapt your lifestyle to protect them. By following a healthy diet, becoming active, and making other sound lifestyle choices, individuals can reduce their risk of developing chronic diseases, or better manage their condition to prevent further complications.

Discussion Starter

1. Assess your risk for developing one of the four chronic diseases discussed in this section. Which risk factors can be modified? Which risk factors can't be modified? What can you do to lessen the chance that you will develop the disease?

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16.2: Behavior Change- The Transtheoretical Model

Learning Objective

Explain...

Changing Your Behavior

Living a sustainable lifestyle and achieving optimal health is not easy. Taking steps to exercise more, eat healthier foods, and work harder to avoid food contamination may involve making major changes in your life. However, change is a process, and researchers have long studied the various stages of that process, as well as what helps or hinders it. While creating and implementing change is not easy, the more conscious you are of the process, and the more you prepare, the greater the chances are for success. Learning about the different stages of behavioral change can help you take a proactive approach to living a sustainable lifestyle.

The Transtheoretical Model of Behavioral Change

The Transtheoretical Model of Behavioral Change identifies the five stages of change, along with things that can help people move through these different stages. It also includes strategies which help people make, create, and continue behavioral change. Learning about these different stages and techniques helps you decide how to best approach making healthy changes in your life.

The five stages of the Transtheoretical Model of Behavioral Change are (Figure 16.2.1):

1. **Precontemplation.** At this stage, an individual has no plans to make any changes, and may not be aware that change is needed. For example, a person who has never thought of eating healthier or being more active is in the precontemplation stage. In this stage, a person often underestimates the pros of changing, and underestimates the cons of maintaining the status quo.
2. **Contemplation.** An individual begins to see the importance of altering behavior, and plans to do so within the next six months. Someone who has realized that they need to add more physical activity to their life, but hasn't made any concrete plans to start doing it, is in the contemplation stage. Although they may be more aware of the benefits of change, the individual may still exaggerate the negative aspects of change.
3. **Preparation.** At this stage, an individual becomes serious about making a change, and plans to implement that change within thirty days. The person may have already started to alter behavior, or told friends about any plans or intentions. For example, someone who wants to eat better and has started gathering healthier recipes is in the preparation stage.
4. **Action.** At this point, an individual is in the midst of change or has made a consistent change in behavior within the past six months. For example, someone in the action stage would have started eating better and exercising on a regular basis.
5. **Maintenance.** At this final stage, an individual has successfully changed their behavior for six months or more and intends to maintain it in the future.



Figure 16.2.1: This is a graphic representation of the "Stages of Change" in the Transtheoretical Model of Behavior Change. from Philciaccio (via Wikipedia).

Adopting a healthier lifestyle requires changes not only in behavior, but also in attitude and perception. The Transtheoretical Model calls them *decisional balance* and *self-efficacy*. Decisional balance means a person has realized that the benefits of making healthy changes outweigh any risks. Self-efficacy means a person has self-belief and the confidence to make and maintain positive changes. Both decisional balance and self-efficacy help people progress through the different stages of change. The Theoretical Model of Behavioral Change also includes ten techniques and strategies for bringing about change:

1. **Consciousness-raising.** Different methods that are used to raise awareness of healthier choices.
2. **Dramatic Relief.** The use of emotions through testimonials, role-playing, and the media to support change.
3. **Environmental Reevaluation.** Helping people become aware of how they affect others, and how a change on their part can also help those around them.

4. **Social Liberation.** Helping individuals realize that society may be more welcoming if they change their behavior.
5. **Self-Liberation.** Allowing people to believe in their ability to change, and make a commitment to it.
6. **Helping Relationships.** Providing connections between people seeking positive change with others who support their efforts.
7. **Counterconditioning.** Finding healthier substitutes for the unhealthy behavior.
8. **Reinforcement Management.** Increasing rewards for healthy behavior and reducing those for negative behavior.
9. **Stimulus Control.** Being aware of and eliminating cues for unhealthy behavior, and replacing them with cues for healthy choices.
10. **Self-reevaluation.** Changing your self-image to fit with a newer, healthier lifestyle.

Prochaska and colleagues state that their research related to the transtheoretical model shows that interventions to change behavior are more effective if they are "stage-matched," that is, "matched to each individual's stage of change (Figure 16.2.2).

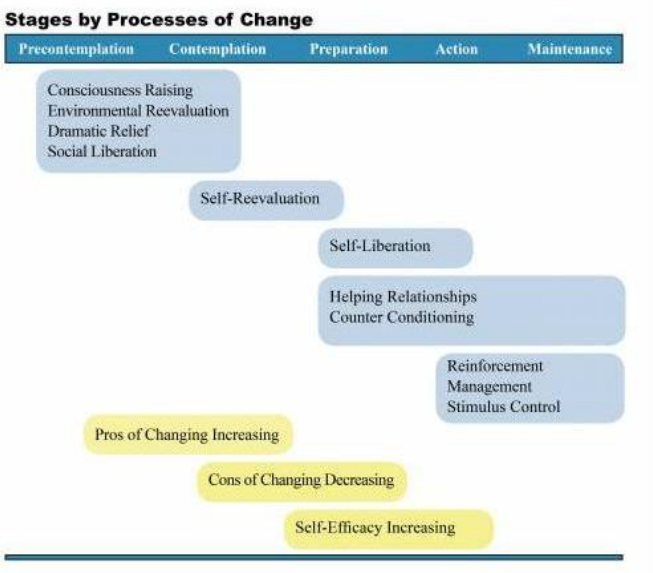


Figure 16.2.2: Processes of Change. from Wikipedia

Some of these processes of change are more effective at different points in the process. A person who is not even contemplating change could tune out emotional appeals or reinforcement management. However, combining knowledge of the change process with the effective use of strategies can help everyone turn their good intentions into healthier lifestyles.Center for Health Communications Research. “Transtheoretical Model (Stages of Change).” © 2009 The Regents of University of Michigan. Accessed December 21, 2011. chcr.umich.edu/how_we_do_it/h..._document_view.

Key Takeaways

Living a sustainable lifestyle can help you to work toward achieving optimal health. There are a number of steps you can take to promote sustainable practices, such as buying locally grown food, eating a plant-based diet, and becoming aware of food and nutrition issues in your community. The Transtheoretical Model of Behavioral Change outlines the different stages of the process of change, and provides tools and techniques to enable major changes.

Discussion Starter

1. Think of a change you might want to make in your life to become healthier, and discuss ways you can use the transtheoretical model to make this change.

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16.3: Foodborne Illness

Learning Objectives

- Describe the ideal environment for microorganisms to reproduce.
- Give examples of bacteria, viruses, parasites, and molds that have the potential to cause foodborne illness.
- Discuss government efforts to protect the health of the population, and precautions consumers can take to protect themselves.

Foodborne illness is another 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. 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.Centers for Disease Control and Prevention. "Food Safety at CDC." Last updated June 28, 2011. http://www.cdc.gov/foodsafety/facts.html. 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.

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.Centers for Disease Control and Prevention. "Food Safety at CDC." Last updated June 28, 2011. http://www.cdc.gov/foodsafety/facts.html. Most are food infections, which means they are caused from food contaminated by microorganisms, such as bacteria, by microscopic animals called parasites, or by viruses. The infection then grows inside the body and becomes the source of symptoms. Food infections can be sporadic and often are not reported to physicians. However, ocassional 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.World Health Organization. “Food Safety and Foodborne Illness.” *Fact Sheet*, no. 237. Last reviewed March 2007. www.who.int/mediacentre/factsheets/fs237/en/.

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 7.0 pH and not many will grow below 4.0 pH. Examples of higher pH foods include meat, seafood, milk, and corn. Examples of low pH foods include citrus fruits, sauerkraut, tomatoes, and pineapples.
- **Nutrient Content.** Microorganisms need protein, starch, sugars, fats, and other compounds to grow. Typically high-protein foods are better for bacterial growth.

Food Intoxication

Other kinds of foodborne illness are food intoxications, which are caused by natural toxins or harmful chemicals. These and other unspecified agents are major contributors to episodes of acute gastroenteritis and other kinds of foodborne illness.Scallan, E. et al. “Foodborne Illness Acquired in the United States—Unspecified Agents.” *Emerg Infect Diseases* 17, no. 1. Like pathogens, toxins and chemicals can be introduced to food during cultivation, harvesting, processing, or distribution. Some toxins can lead to symptoms that are also common to food infection, such as abdominal cramping, while others can cause different kinds of symptoms and complications, some very severe. For example, mercury, which is sometimes found in fish, can cause neurological damage in infants and children. Exposure to cadmium can cause kidney damage, typically in elderly people.

The Causes of Food Contamination

Both food infections and food intoxications can create a burden on health systems, when patients require treatment and support, and on food systems, when companies must recall contaminated food or address public concerns. It all begins with the agent that causes the contamination. When a person ingests a food contaminant, it travels to the stomach and intestines. There, it can interfere with the body’s functions and make you sick. In the next part, we will focus on different types of food contaminants and examine common microbes, toxins, chemicals, and other substances that can cause food infections and intoxications. Let’s begin with pathogens, which include bacteria and viruses. About one hundred years ago, typhoid fever, tuberculosis, and cholera were common diseases caused by food and water contaminated by pathogens. Over time, improvements in food processing and water treatment eliminated most of those problems in North America. Today, other bacteria and viruses have become common causes of food infection.

Bacteria

All foods naturally contain small amounts of bacteria. However, poor handling and preparation of food, along with improper cooking or storage can multiply bacteria and cause illness. In addition, bacteria can multiply quickly when cooked food is left out at room temperature for more than a few hours. Most bacteria grow undetected because they do not change the color or texture of food or produce a bad odor. Freezing and refrigeration slow or stop the growth of bacteria, but does not destroy the bacteria completely. The microbes can reactivate when the food is taken out and thawed.

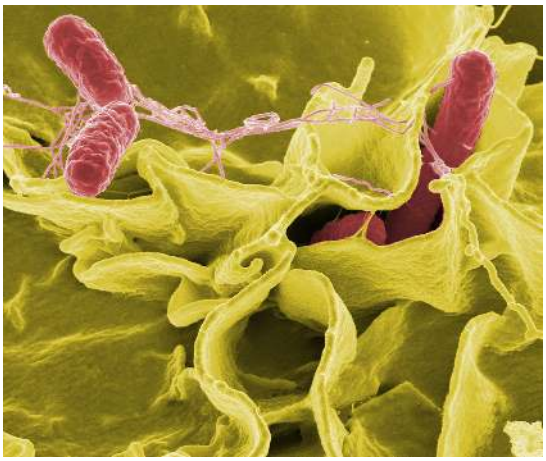


Figure 16.3.1: Salmonella was first identified in 1885 and many types of this kind of bacteria exist. The incidence of Salmonella infections has risen dramatically in the past few decades. Color-enhanced scanning electron micrograph showing Salmonella Typhimurium (red) invading cultured human cells (Credit: Rocky Mountain Laboratories, NIAID, NIH). Image is public domain.

Many different kinds of bacteria can lead to food infections. One of the most common is *Salmonella*, which is found in the intestines of birds, reptiles, and mammals. *Salmonella* can spread to humans via a variety of different animal-origin foods, including meats, poultry, eggs, dairy products, and seafood. The disease it causes, salmonellosis, typically brings about fever, diarrhea, and abdominal cramps within twelve to seventy-two hours after eating. Usually, the illness lasts four to seven days, and most people recover without treatment. However, in individuals with weakened immune systems, *Salmonella* can invade the bloodstream and lead to life-threatening complications, such as a high fever and severe diarrhea. Centers for Disease Control and Prevention. “Salmonella.” Last updated December 19, 2011. http://www.cdc.gov/salmonella/.

The bacterium *Listeria monocytogenes* is found in soft cheeses, unpasteurized milk, and seafood. It causes a disease called listeriosis that can bring about fever, headache, nausea, and vomiting. *Listeria monocytogenes* mostly affects pregnant women, newborns, older adults, and people with cancer and compromised immune systems.

The food infection *E. coli* is caused by *Escherichia coli*. Sources include raw or undercooked meat, raw vegetables, unpasteurized milk, minimally processed ciders and juices, and contaminated drinking water. Symptoms can occur a few days after eating, and include watery and bloody diarrhea, severe stomach cramps, and dehydration. More severe complications may include colitis, neurological symptoms, stroke, and hemolytic uremic syndrome. In young children, an *E. coli* infection can cause kidney failure and death.

The bacterium *Clostridium botulinum* causes botulism. Sources include improperly canned foods, lunch meats, and garlic. An infected person may experience symptoms within four to thirty-six hours after eating. Symptoms could include nerve dysfunction, such as double vision, inability to swallow, speech difficulty, and progressive paralysis of the respiratory system. Botulism can also be fatal.

Campylobacter jejuni causes the disease campylobacteriosis. It is the most commonly identified bacterial cause of diarrhea worldwide. Consuming undercooked chicken, or food contaminated with the juices of raw chicken, is the most frequent source of this infection. Other sources include raw meat and unpasteurized milk. Within two to five days after consumption, symptoms can begin and include diarrhea, stomach cramps, fever, and bloody stools. The duration of this disease is about seven to ten days.

The food infection shigellosis is caused by *Shigella*, of which there are several types. Sources include undercooked liquid or moist food that has been handled by an infected person. The onset of symptoms occurs one to seven days after eating, and can include stomach cramps, diarrhea, fever, and vomiting. Another common symptom is blood, pus, or mucus in stool. Once a person has had shigellosis, the individual is not likely to get infected with that specific type again for at least several years. However, they can still become infected with other types of *Shigella*.

Staphylococcus aureus causes staphylococcal food poisoning. Food workers who carry this kind of bacteria and handle food without washing their hands can cause contamination. Other sources include meat and poultry, egg products, cream-filled pastries, tuna, potato and macaroni salad, and foods left unrefrigerated for long periods of time. Symptoms can begin thirty minutes to eight hours after eating, and include diarrhea, vomiting, nausea, stomach pain, and cramps. This food infection usually lasts one to two days.

Found in raw oysters and other kinds of seafood, *Vibrio vulnificus* belongs to the same family as the bacteria which cause cholera. This food contaminant can result in the *Vibrio* infection. Symptoms can begin anywhere from six hours to a few days after consumption, and include chills, fever, nausea, and vomiting. This disease is very dangerous and can result in fatalities, especially in people with underlying health problems.Centers for Disease Control and Prevention. “Food Safety at CDC.” Last updated June 28, 2011. http://www.cdc.gov/foodsafety/facts.html.

Viruses

Viruses are another type of pathogen that can lead to food infections, however they are less predominant than bacteria. **Hepatitis A** is one of the more well-known food-contaminating viruses. Sources include raw shellfish from polluted water, and food handled by an infected person. This virus can go undetected for weeks and, on average, symptoms do not appear until about one month after exposure. At first, symptoms include malaise, loss of appetite, nausea, vomiting, and fever. Three to ten days later, additional symptoms can manifest, including jaundice and darkened urine. Severe cases of a hepatitis A can result in liver damage and death.

The most common form of contamination from handled foods is the **norovirus**, which is also known as the Norwalk-like virus, or the calicivirus. Sources include raw shellfish from polluted water, salads, sandwiches, and other ready-to-eat foods handled by an infected person. The norovirus causes gastroenteritis and within one to three days it leads to symptoms, such as nausea, vomiting, diarrhea, stomach pain, headache, and a low-grade fever.Centers for Disease Control and Prevention. “Food Safety at CDC.” Last updated June 28, 2011. http://www.cdc.gov/foodsafety/facts.html.

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.Centers for Disease Control and Prevention. “Parasites.” Last updated November 2, 2010. http://www.cdc.gov/parasites/food.html.

Mold Toxins

Warm, humid, or damp conditions encourage mold to grow on food. Molds are microscopic fungi that live on animals and plants. No one knows how many species of fungi exist, but estimates range from ten- to three-hundred thousand. Unlike single-celled bacteria, molds are multicellular, and under a microscope look like slender mushrooms. They have stalks with spores that form at the ends. The spores give molds their color and can be transported by air, water, or insects. Spores also enable mold to reproduce. Additionally, molds have root-like threads that may grow deep into food and be difficult to see. The threads are very deep when a food shows heavy mold growth. Foods that contain mold may also have bacteria growing alongside it.



Figure 16.3.2: Mold can grow on fruits, vegetables, grains, meats, poultry, and dairy products, and typically appears as gray or green “fur.” Moldy nectarines that were in a refrigerator. The nectarine with black mold is also affecting the nectarine underneath. from Roger McLassus 1951.

Some molds, like the kind found in blue cheese, are desirable in foods, while other molds can be dangerous. The spores of some molds can cause allergic reactions and respiratory problems. In the right conditions, a few molds produce mycotoxins, which are natural, poisonous substances that can make you sick if they are consumed. Mycotoxins are contained in and around mold threads, and in some cases, may have spread throughout the food. The Food and Agriculture Organization of the United Nations estimates that mycotoxins affect 25% of the world’s food crops. They are found primarily in grains and nuts, but other sources include apples, celery, and other produce.

The most dangerous mycotoxins are **aflatoxins**, which are produced by strains of fungi called *Aspergillus* under certain temperature and humidity conditions. Contamination has occurred in peanuts, tree nuts, and corn. Aflatoxins can cause aflatoxicosis in humans, livestock, and domestic animals. Symptoms include vomiting and abdominal pain. Possible complications include liver failure, liver cancer, and even death. Many countries try to limit exposure to aflatoxins by monitoring their presence on food and feed products.US Department of Agriculture, Food Safety and Inspection Service. “Molds on Food: Are They Dangerous?” Last modified March 4, 2010. www.fsis.usda.gov/FactSheets/Molds_On_Food/.

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.US Department of Agriculture, Food Safety and Inspection Service. “Molds on Food: Are They Dangerous?” Last modified March 4, 2010. www.fsis.usda.gov/FactSheets/Molds_On_Food/.

Pesticides

Pesticides are important in food production to control diseases, weeds, insects, and other pests. They protect crops and ensure a large yield. However, synthetic pesticides can leave behind residues, particularly on produce, that can be harmful to human health. Foods that contain the highest levels of pesticide residue include conventionally-grown peaches, apples, bell peppers, celery, nectarines, strawberries, cherries, pears, spinach, lettuce, and potatoes. Foods that contain the lowest levels of pesticide residue include avocadoes, pineapples, bananas, mangoes, asparagus, cabbage, and broccoli.Hoffman, M. MD. “Safer Foods for a Healthier You.” Web MD. © 2009 WebMD, LLC. http://www.webmd.com/health-ehome-9/pesticides-hormones-in-food. In many cases, the amount of pesticide exposure is too small to pose a risk. However, harmful exposures can lead to certain health problems and complications, including cancer. Also, infants and young children are more susceptible to the hazards of pesticides than adults. In addition, using synthetic pesticides, herbicides, and fertilizers contributes to soil and water pollution and can be hazardous to farm workers.

To protect the public and their workers, many farmers now rely on alternatives to synthetic pesticide use, including crop rotation, natural pesticides, and planting nonfood crops nearby to lure pests away. Some consumers choose to reduce their exposure to pesticides by purchasing organic produce. Organic foods are grown or produced without synthetic pesticides or fertilizer, and all

growers and processors must be certified by the US Department of Agriculture (USDA). However, conventionally-grown produce should be 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.Ministry of the Environment, Government of Japan. “Minamata Disease: The History and Measures.” © 2002. Accessed December 21, 2011. http://www.env.go.jp/en/chemi/hs/minamata2002/.

PCBs, or polychlorinated biphenyls, are man-made organic compounds that are used commercially. Like methyl mercury, higher concentrations of this contaminant are found in predatory fish. Health effects include physical and neurological development in children, and this compound is potentially a carcinogen. PCB contamination also can affect the immune, reproductive, nervous, and endocrine systems.US Environmental Protection Agency. “Health Effects of PCBs.” Last updated August 08, 2008. http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/effects.htm.

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16.4: Food Safety

Learning Objectives

Explain...

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, the USDA, and Health Canada, among other organizations.

Efforts on the Governmental Level

A number of government agencies work to ensure food safety and to protect the public from foodborne illness. The USDA and the FDA enforce laws regarding the safety of domestic and imported food. In addition, the Federal Food, Drug, and Cosmetic Act of 1938 gives the FDA authority over food ingredients. The CDC tracks outbreaks, identifies the causes of food infection and intoxication, and recommends ways to prevent foodborne illness. Other government agencies that play a role in protecting the public include the Food Safety and Inspection Service, a division of the USDA, which enforces laws regulating meat and poultry safety. The Agricultural Research Service, which is the research arm of the USDA, investigates a number of agricultural practices, including those related to animal and crop safety. The National Institute of Food and Agriculture conducts research and education programs on food safety for farmers and consumers. Also, the Environmental Protection Agency (EPA) regulates public drinking water.

Government agencies also monitor the use of pesticides. The EPA approves pesticides and other chemicals used in agriculture, and sets limits on how much residue can remain on food. The FDA analyzes food for surface residue and waxes. Processing methods can either reduce or concentrate pesticide residue in foods. Therefore, the Food Quality Protection Act, which was passed in 1996, requires manufacturers to show that pesticide levels are safe for children.

In Canada, Health Canada works with local governments, industries, and consumers to establish food safety throughout the nation. The agency's scientists assess health risks from foodborne contaminants, conduct research, and evaluate data to better understand the effects of pathogens, chemicals, and other foodborne agents on the body. Health Canada also monitors the levels of contaminants in foods and estimates the exposure of consumers. Another organization, the Canadian Food Inspection Agency, enforces the safety policies and standards set by Health Canada. They safeguard livestock, along with crops and other plants, to protect the public.

Efforts within the Food Industry

As discussed in Chapter 14, the Hazard Analysis Critical Control Points (HACCP) is a system within the food industry designed to promote food safety and prevent contamination by identifying all areas in food production and retail where contamination could occur. Companies and retailers determine the points during processing, packaging, shipping, or shelving where hazards could occur. Those companies or retailers must then take measures to prevent, control, or eliminate the potential for food contamination. The USDA requires the food industry to follow HACCP for meat and poultry, while the FDA requires it for seafood, low-acid canned-food, and juice. HACCP is voluntary for all other food products.

Efforts on the Consumer Level: What You Can Do

Consumers can also take steps to prevent foodborne illness and protect their health. Although you can often detect when mold is present, you can't see, smell, or taste bacteria or other agents of foodborne disease. Therefore, it is crucial to take measures to protect yourself from disease. The four most important steps for handling, preparing, and serving food are:

1. **Clean.** Wash hands thoroughly. Clean surfaces often and wash utensils after each use. Wash fruits and vegetables (even if you plan to peel them).
2. **Separate.** Don't cross-contaminate food during preparation and storage. Use separate cutting boards for produce and for meat, poultry, seafood, and eggs. Store food products separately in the refrigerator.
3. **Cook.** Heat food to proper temperatures. Use a food thermometer to check the temperature of food while it is cooking. Keep food hot after it has been cooked.

4. **Chill.** Refrigerate any leftovers within two hours. Never thaw or marinate food on the counter. Know when to keep food and when to throw it out. It can be helpful to check the website http://www.stilltasty.com, which explains how long refrigerated food remains fresh.US Department of Health and Human Services. “Keep Food Safe.” Food Safety.gov. Accessed December 21, 2011. http://www.foodsafety.gov/keep/index.html.

Buying Food

It is best to buy your food from reputable grocers with clean, sanitary facilities, that keep products at appropriate temperatures. Consumers should examine food carefully before they purchase it. It is important to look at food in glass jars, check the stems on fresh produce, and avoid bruised fruit. Do not buy canned goods with dents or bulges, which are at risk for contamination with *Clostridium botulinum*. Fresh meat and poultry are usually free from mold, but cured and cooked meats should be examined carefully. Also, avoid torn, crushed, or open food packages, and do not buy food with frost or ice crystals, which indicates that the product has been stored for a long time, or thawed and refrozen. It is also a good idea to keep meat, poultry, seafood, and eggs separate from other items in your shopping cart as you move through the grocery store.



Video 16.4.1: Start at the Store: Prevent Foodborne Illness. This video provides tips to follow when selecting and purchasing food at the supermarket to help to prevent foodborne illness and protect your health (click to see video).

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.California Department of Pesticide Regulation. “Pesticides and Food: How We Test for Safety.” *Pesticide Info: What You Should Know about Pesticides*, no. #E09/REV. Accessed December 21, 2011. www.cdpr.ca.gov/docs/dept/factshts/residu2. 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 a temperature that is high enough to kill bacteria. You cannot judge the state of “cooked” by color and texture alone. Instead, use a food thermometer to be sure. The appropriate minimum cooking temperature varies depending on the type of food. Seafood should be cooked to an internal temperature of 145°F, beef, lamb, and pork to 160°F, ground chicken and turkey to 165°F, poultry breasts to 170°F, and whole poultry and thighs to 180°F. When microwaving, rotate the dish and stir contents several times to ensure even cooking.

Serving Food

After food has been cooked, the possibility of bacterial growth increases as the temperature drops. So, food should be kept above the safe temperature of 140°F, using a heat source such as a chafing dish, warming tray, or slow cooker. Cold foods should be kept at 40°F or lower. When serving food, keep it covered to block exposure to any mold spores hanging in the air. Use plastic wrap to cover foods that you want to remain moist, such as fresh fruits, vegetables, and salads. After a meal, do not keep leftovers at room temperature for more than two hours. They should be refrigerated as promptly as possible. It is also helpful to date leftovers, so they can be used within a safe time, which is generally three to five days when stored in a refrigerator.

Key Takeaways

Foodborne illness is caused by pathogens, such as bacteria and viruses, toxins, such as those produced by molds and poisonous mushrooms, and chemical contaminants, such as pesticide residues and pollutants. A number of government agencies work to regulate food, manage outbreaks, and inform the public about foodborne illness and food safety. Consumers also should take measures to protect their health, including following the rules for four key steps: clean, separate, cook, and chill.

Discussion Starter

1. Discuss tactics that government agencies or consumer groups could take to educate the public about food safety. What key points do you think consumers need to know about foodborne illness and food safety? How do you think government organizations or other groups can best get that information out to the public?

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16.5: Start Your Sustainable Future Today

Learning Objectives

- Discuss forms of activism in areas of food and nutrition.
- List steps individuals can take to support sustainable agriculture.

As we near the end of our journey in the world of health and nutrition, let's address how to adjust your lifestyle today to ensure better health and wellness tomorrow. Adopting sustainable practices can go a long way toward helping you achieve optimal health, while also helping to protect the health of our planet. Remember, that sustainability involves meeting present nutritional needs while preserving resources for the future. It includes agricultural practices and processes, along with the choices that consumers make when they shop for their food. Ideally, sustainable practices include methods that are healthy, conserve the environment, protect livestock, respect food industry workers, provide fair wages to farmers, and support farming communities. When a practice or a process is sustainable, it can be maintained for decades, or even centuries, to come.

Living a Sustainable Lifestyle

There are a number of steps you can take to live a more sustainable lifestyle. Utilizing an environmentally-friendly approach to good nutrition is a great way to remain and stay healthy. As an initial step, you might try to buy more whole foods rather than processed foods. You might also drink more water, rather than sodas and juices with added sugar. It is also a good idea to drink from a reusable water bottle to avoid adding more plastic to your local landfill, not to mention saving the fuel it takes to ship bottles of water. Here are some other suggestions to live a more sustainable lifestyle:

- **Learn more about food.** Learn about your local food system, what is native to the area, what is imported or shipped in, how food moves from farms to processors to retail in your area, and what practices are used. Read labels to see where food comes from and what the growing and processing practices are. You might also try taking a cooking class to learn more about food in general.
- **Eat a plant-based diet.** A plant-based diet is not necessarily vegetarian or vegan; it simply emphasizes whole grains, fruits, vegetables, and legumes over meat and poultry. Plant-based foods are good sources of carbohydrates, protein, fat, vitamins, and minerals. They also help to decrease your risk for cancer and other chronic conditions.
- **Support local farmers.** Purchase more locally grown food to promote sustainability. This could involve going to a farmer's market or a nearby farm. Locally grown food requires less fossil fuel because it does not have to travel great distances. Locally grown food also puts money back into your community and helps farmers in your area. Shopping at a farmer's market or a local farm may also provide an opportunity to talk to the farmer who grew the food to learn more about what you put on your plate.
- **Join a community garden.** You can't get more local than food that is grown in your own backyard. Consider growing your own food, or trying a community garden if you do not have the space at your home. Produce from a local garden will not only be fresher, it will often taste better. In addition, it will provide an opportunity to get to know like-minded individuals in your community.
- **Help spread the word.** Talk to friends and family members about food, nutrition, and living a sustainable lifestyle. Also, pay attention to food and nutrition policy at the federal, state, and local levels. Take a look at what foods are available in your community. Are there supermarkets or corner stores? What is available in the university dining hall? If healthy options are lacking, can you talk to someone to bring about changes?

Tools for Change

Another option to support local farmers is to sign up for a CSA (community-supported agriculture). Prior to a planting season, consumers who join a CSA purchase a produce share from a local farmer. When harvesting begins, farmers provide in-season, locally grown vegetables to shareholders at a local drop spot each week throughout the growing season. Some CSAs also include fruit, dairy products, meat, and more. CSA farmers often will allow you to visit the farm to learn more about the crops they grow or even volunteer to help with the harvest. Joining a CSA provides a direct connection between the local farming community and you.

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16.6: Food Insecurity

Learning Objectives

Identify...

Addressing Hunger

Government agencies also play an important role in addressing hunger via federal food-assistance programs. The agencies provide debit cards (formerly distributed in the form of food vouchers or food stamps) to consumers to help them purchase food and they also provide other forms of aid to low-income adults and families who face hunger and nutritional deficits. This topic will be discussed in greater detail later in this chapter.

Hunger relates to appetite and is the body's response to a need for nourishment. Through stomach discomfort or intestinal rumbling, the body alerts the brain that it requires food. This uneasy sensation is easily addressed with a snack or a full meal. However, the term "hunger" also relates to a weakened condition that is a consequence of a prolonged lack of food. People who suffer from this form of hunger typically experience malnourishment, along with poor growth and development.

Hunger

Adequate food intake that meets nutritional requirements is essential to achieve a healthy, productive lifestyle. However, millions of people in North America, not to mention globally, go hungry and are malnourished each year due to a recurring and involuntary lack of food. The economic crisis of 2008 caused a dramatic increase in hunger across the United States.[1]

In 2010, 925 million people around the world were classified as hungry. Although this was a decrease from a historic high of more than one billion people from the previous year, it is still an unbearable number. Every night, millions and millions of people go to sleep hungry due to a lack of the money or resources needed to acquire an adequate amount of food. This graph shows the division of hungry people around the globe. A number of terms are used to categorize and classify hunger. Two key terms, food security and food insecurity, focus on status and affect hunger statistics. Another term, malnutrition, refers to the deficiencies that a hungry person experiences.

Food Security

Most American households are considered to be food secure, which means they have adequate access to food and consume enough nutrients to achieve a healthy lifestyle. However, a minority of US households experiences food insecurity at certain points during the year, which means their access to food is limited due to a lack of money or other resources. This graphic shows the percentage of food-secure and food-insecure households in the United States during the year 2010.

Food Insecurity

Food insecurity is defined as not having adequate access to food that meets nutritional needs. According to the USDA, about 48.8 million people live in food-insecure households and have reported multiple indications of food access problems. About sixteen million of those have "very low food security," which means one or more people in the household were hungry at some point over the course of a year due to the inability to afford enough food. The difference between low and very low food security is that members of low insecurity households have reported problems of food access, but have reported only a few instances of reduced food intake, if any.[2] African American and Hispanic households experience food insecurity at much higher rates than the national average.[3]

Households with limited resources employ a variety of methods to increase their access to adequate food. Some families purchase junk food and fast food—cheaper options that are also very unhealthy. Other families who struggle with food security supplement the groceries they purchase by participating in government assistance programs. They may also obtain food from emergency providers, such as food banks and soup kitchens in their communities.

Malnutrition

A person living in a food-insecure household may suffer from malnutrition, which results from a failure to meet nutrient requirements. This can occur as a result of consuming too little food or not enough key nutrients. There are two basic types of malnutrition. The first is macronutrient deficiency and relates to the lack of adequate protein, which is required for cell growth,

maintenance, and repair. The second type of malnutrition is micronutrient deficiency and relates to inadequate vitamin and mineral intake.[4] Even people who are overweight or obese can suffer from this kind of malnutrition if they eat foods that do not meet all of their nutritional needs.

Worldwide, three main groups are most at risk of hunger: the rural poor in developing nations who also lack access to electricity and safe drinking water, the urban poor who live in expanding cities and lack the means to buy food, and victims of earthquakes, hurricanes, and other natural and man-made catastrophes.[5]

In the United States, there are additional subgroups that are at risk and are more likely than others to face hunger and malnutrition. They include low-income families and the working poor, who are employed but have incomes below the federal poverty level.

Senior citizens are also a major at-risk group. Many elderly people are frail and isolated, which affects their ability to meet their dietary requirements. In addition, many also have low incomes, limited resources, and difficulty purchasing or preparing food due to health issues or poor mobility. As a result, more than six million senior citizens in the United States face the threat of hunger.[6]

One of the groups that struggles with hunger are the millions of homeless people across North America. According to a recent study by the US Conference of Mayors, the majority of reporting cities saw an increase in the number of homeless families.[7] Hunger and homelessness often go hand-in-hand as homeless families and adults turn to soup kitchens or food pantries or resort to begging for food.

Rising hunger rates in the United States particularly affect children. Nearly one out of four children, or 21.6 percent of all American children, lives in a food-insecure household and spends at least part of the year hungry.[8] Hunger delays their growth and development and affects their educational progress because it is more difficult for hungry or malnourished students to concentrate in school. In addition, children who are undernourished are more susceptible to contracting diseases, such as measles and pneumonia.[9]

Government Programs

The federal government has established a number of programs that work to alleviate hunger and ensure that many low-income families receive the nutrition they require to live a healthy life. A number of programs were strengthened by the passage of the Healthy, Hunger-Free Kids Act of 2010. This legislation authorized funding and set the policy for several key core programs that provide a safety net for food-insecure children across the United States.

The federal poverty level (FPL) is used to determine eligibility for food-assistance programs. This monetary figure is the minimum amount that a family would need to acquire shelter, food, clothing, and other necessities. It is calculated based on family size and is adjusted for annual inflation. Although many people who fall below the FPL are unemployed, the working poor can qualify for food programs and other forms of public assistance if their income is less than a certain percentage of the federal poverty level, along with other qualifications.

USDA Food Assistance Programs

Government food and nutrition assistance programs that are organized and operated by the USDA work to increase food security. They provide low-income households with access to food, the tools for consuming a healthy diet, and education about nutrition. The USDA monitors the extent and severity of food insecurity via an annual survey. This contributes to the efficiency of food assistance programs as well as the effectiveness of private charities and other initiatives aimed at reducing food insecurity.[10]

The Supplemental Nutrition Assistance Program

Formerly known as the Food Stamp Program, the Supplemental Nutrition Assistance Program (SNAP) provides monthly benefits for low-income households to purchase approved food items at authorized stores. Clients qualify for the program based on available household income, assets, and certain basic expenses. In an average month, SNAP provides benefits to more than forty million people in the United States.[11] The program provides Electronic Benefit Transfers (EBT) which work similarly to a debit card. Clients receive a card with a certain allocation of money for each month that can be used only for food. In 2010, the average benefit was about $134 per person, per month and total federal expenditures for the program were $68.2 billion.[12]

The Special, Supplemental Program for Women, Infants, and Children

The Special, Supplemental Program for Women, Infants and Children (WIC) provides food packages to pregnant and breastfeeding women, as well as to infants and children up to age five, to promote adequate intake for healthy growth and development. Most

state WIC programs provide vouchers that participants use to acquire supplemental packages at authorized stores. In 2010, WIC served approximately 9.2 million participants per month at an average monthly cost of about forty-two dollars per person.[13]

The National School Lunch Program

The National School Lunch Program (NSLP) and School Breakfast Program (SBP) ensure that children in elementary and middle schools receive at least one healthy meal each school day, or two if both the NSLP and SBP are provided. According to the USDA, these programs operate in over 101,000 public and nonprofit private schools and residential child-care institutions.[14] In 2010, the programs provided meals to an average of 31.6 million children each school day. Fifty-six percent of the lunches served were free, and an additional 10 percent were provided at reduced prices.

Meals on Wheels

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

Nutrition and Your Health

The adage, “you are what you eat,” seems to be more true today than ever. In recent years, consumers have become more conscientious about the decisions they make in the supermarket. Organically grown food is the fastest growing segment of the food industry. Also, farmers’ markets and chains that are health-food-oriented are thriving in many parts of North America. Shoppers have begun to pay more attention to the effect of food on their health and well-being. That includes not only the kinds of foods that they purchase, but also the manner in which meals are cooked and consumed. The preparation of food can greatly affect its nutritional value. Also, studies have shown that eating at a table with family members or friends can promote both health and happiness.Query 16.6.1

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16.7: Careers in Nutrition

Learning Objectives

- List some of the jobs available to students who are interested in a career in food and nutrition.

If you are considering a career in nutrition, it is important to understand the opportunities that may be available to you. Both dietitians and nutritionists provide nutrition-related services to people in the private and public sectors. A dietitian is a healthcare professional who has registered credentials and can provide nutritional care in the areas of health and wellness for both individuals and groups. A nutritionist is an unregistered professional who may have the credentials of a dietitian or may have acquired the knowledge via other avenues. People in both professions work to apply nutritional science, using evidence-based best practices, to help people nourish their bodies and improve their lives.

Becoming a registered dietitian (RD or RDN) requires a Bachelor's and/or Master's degree in dietetics, including courses in biology, chemistry, biochemistry, microbiology, anatomy and physiology, nutrition, and food-service management. Other suggested courses include economics, business, statistics, computer science, psychology, and sociology. In addition, people who pursue this path must complete a dietetic internship (similar to a medical residency) and pass a national board exam. Also, some states have licensure that requires additional forms and documentation. To become a registered dietetic technician (DTR) you must complete a dietetic technician program that involves supervised practice. (1,2)

Working in Nutrition

Dietitians and nutritionists plan food and nutrition programs, promote healthy eating habits, and recommend dietary modifications. For example, a dietitian might teach a patient with hypertension how to follow the DASH diet and reduce their sodium intake. Nutrition-related careers can be extremely varied. Some individuals work in the government, while others are solely in the private sector. Some jobs in nutrition focus on working with athletes, while others provide guidance to patients with long-term, life-threatening diseases. But no matter the circumstance or the clientele, working in the field of diet and nutrition focuses on helping people improve their dietary habits by translating nutritional science into food choices.

In the public sector, careers in nutrition span from government work to community outreach. Nutritionists and dietitians who work for the government may become involved with federal food programs, federal agencies, communication campaigns, or creating and analyzing public policy. On the local level, clinical careers include working in hospitals and nursing-care facilities. This requires creating meal plans and providing nutritional guidance to help patients restore their health or manage chronic conditions. Clinical dietitians also confer with doctors and other health-care professionals to coordinate dietary recommendations with medical needs. Nutrition jobs in the community often involve working in public health clinics, cooperative extension offices, and HMOs to prevent disease and promote the health of the local community. Nutrition jobs in the nonprofit world involve anti-hunger organizations, public health organizations, and activist groups.

Nutritionists and dietitians can also find work in the private sector. Increased public awareness of food, diet, and nutrition has led to employment opportunities in advertising, marketing, and food manufacturing. Dietitians working in these areas analyze foods, prepare marketing materials, or report on issues such as the impact of vitamins and herbal supplements. Consultant careers can include working in wellness programs, supermarkets, physicians' offices, gyms, eating disorder treatment, and weight-loss clinics. Consultants in private practice perform nutrition screenings for clients and use their findings to provide guidance on diet-related issues, such as improved athletic ability. Nutrition careers in the corporate world include designing wellness strategies and nutrition components for companies, working as representatives for food or supplement companies, designing marketing and educational campaigns, and becoming lobbyists. Others in the private sector work in food-service management at health-care facilities or at companies and school cafeterias. Sustainable agricultural practices are also providing interesting private sector careers on farms and in food systems. There are employment opportunities in farm management, marketing and sales, compliance, finance, and land surveying and appraisal.

Working toward Tomorrow

Whether you pursue nutrition as a career or simply work to improve your own dietary choices, what you have learned in this course can provide a solid foundation for the future. Remember, your ability to wake up, to think clearly, communicate, hope, dream, go to school, gain knowledge, and earn a living are totally dependent upon one factor—your health. Good health allows you to function normally and work hard to pursue your goals. Yet, achieving optimal health cannot be underestimated. It is a complex process,

involving multiple dimensions of wellness, along with your physical or medical reality. The knowledge you have now acquired is also key. However, it is not enough to pass this nutrition class with good grades. Nutrition knowledge must be applied to make a difference in your life, throughout your life.

Throughout this textbook, we have focused on the different aspects of nutritional science, which helps to optimize health and prevent disease. Scientific evidence provides the basis for dietary guidelines and recommendations. In addition, researchers in the field of nutrition work to advance our knowledge of food production and distribution. Nutritional science also examines the ill effects of malnutrition and food insecurity. The findings that are uncovered today will influence not only what we eat, but how we grow it, distribute it, prepare it, and even enjoy it tomorrow.

Summary and Key Takeaway

There are many paths that one can take to become a professional in the field of nutrition, including working as a nutritionist or becoming a registered dietitian. Some confuse the terms "dietitian" and "nutritionist," and this tends to be erroneous. A nutritionist is a person who educates on matters of food and nutrition impacts on health. In contrast, A dietitian is an expert in the relationship between human nutrition and the regulation of diet; a dietitian alters their patient's nutrition based upon their medical condition and individual needs.

Discussion Starter

1. Compare and contrast nutrition-related careers in the public and private sectors. Discuss which area would most interest you and the reasons why.

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CHAPTER OVERVIEW

17: Macronutrient and Alcohol Metabolism

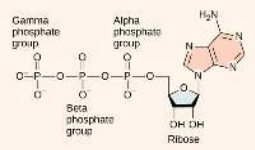


Figure 17.1: Adenosine Triphosphate from Openstax Biology 2e / CC BY 4.0

17.1: Metabolism Basics

17.1.1: Cofactors and Helpers in Metabolic Reactions

17.1.2: ATP as Fuel for Metabolism

17.1.3: How Do the Macronutrients Provide ATP?

17.1.4: Central Aspect of Generating Pyruvate in Energy Metabolism - Glycolysis up close

17.2: Energy Systems

17.2.1: Short-Term Energy- Glycolytic Pathway

17.2.2: Long-Term Energy- Oxidative System

17.3: Carbohydrate Metabolism

17.3.1: Glycolysis

17.3.2: Transition Reaction from Pyruvate into Acetyl CoA (keep!)

17.3.3: Electron Transport Chain (keep!)

17.3.4: Anaerobic Respiration (keep but move to 9.2?)

17.4: Lipid Metabolism

17.4.1: Lipolysis (Triglyceride Breakdown)

17.4.2: Fatty Acid Oxidation (Beta-oxidation)

17.4.3: De novo Lipogenesis (Fatty Acid Synthesis)

17.4.4: Ketone Body Synthesis

17.4.5: Cholesterol Synthesis

17.4.6: Claudia's new lipid page - here Feast or Famine ?

17.5: Protein Metabolism

17.5.1: Transamination, Deamination and Ammonia Removal as Urea

17.5.2: Gluconeogenesis

17.5.3: Protein Turnover/Degradation

17.6: Alcohol Metabolism

17.7: Excretion of Metabolic Waste Products

17.8: Research Highlight - Metabolic Disorders

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17.1: Metabolism Basics

Learning Objectives

- Describe examples of catabolic and anabolic metabolism.

Introduction

You learned in previous chapters about macronutrients, their digestion and absorption. In this chapter, we are taking a closer look 'what the body does with the absorbed nutrients' to promote health and wellbeing; mainly food is converted into cellular energy (as ATP) and occurs in three stages. This energy is used by the body to move muscles (mechanical energy), to generate heat to warm you, to conduct nerve impulses in form of electrical energy, and to produce energy stores in form of glycogen and fat.

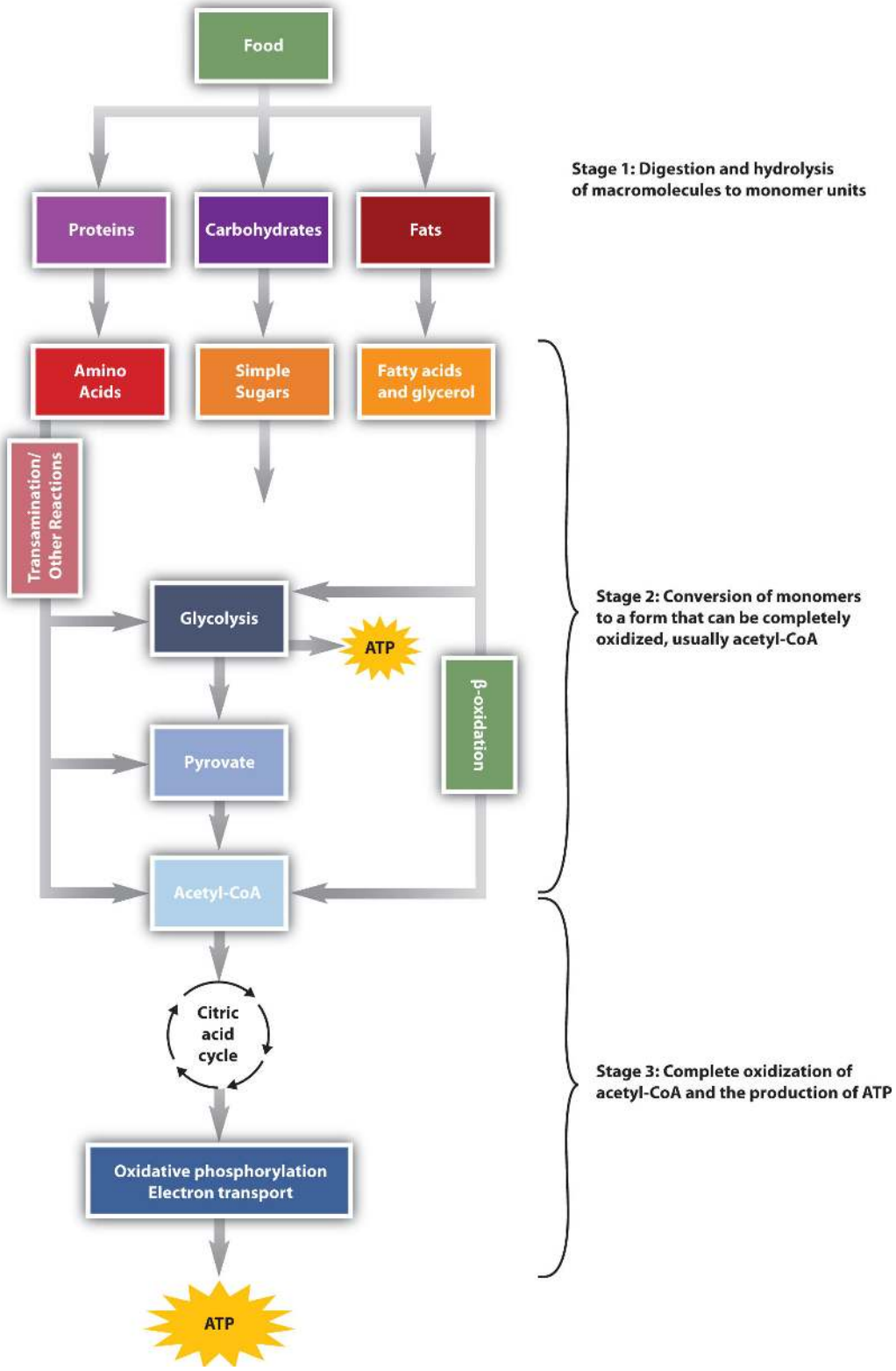


*Figure 9.1 Energy Conversions.1 (Please note that '**pyruvate**' is a metabolite that is generated during glycolysis; hence, please ignore the typo in the figure above)*

At all times, your cells produce a steady supply of energy - either from the foods you eat or from energy stores inside the body; understanding these intricate reactions referred to as 'metabolism', is an important aspect of studying nutrition.

Definition of metabolism

Metabolism consists of all the (bio)chemical processes that occur in living cells. These processes (a.k.a. biochemical reactions) can generally be classified as either anabolic or catabolic. Anabolic means to build, catabolic means to breakdown. If you have trouble remembering the difference between the two, recall that anabolic steroids are what is used to build enormous muscle mass. Metabolism allows the body to convert energy from foods into energy needed for physical activity or building life-sustaining substances.



Figure 9.2 One of these two is taking anabolic steroids, which one would be your guess?2

Introduction to anabolic and catabolic reactions

An **anabolic** pathway requires energy to build something. For example, the body uses a single amino acid to form proteins, excess glucose molecules are combined to make glycogen, and excess fatty acids attach to glycerol molecules to make triglycerides; these reactions involve the formation of new bonds, which requires energy. On the other hand, a **catabolic** pathway generates energy by breaking down something. This is shown in the example below of glucose and glycogen. The same is true for other macronutrients, such as lipid breakdown (or catabolism) into fatty acids and proteins breakdown (or catabolism) into their amino acid components.

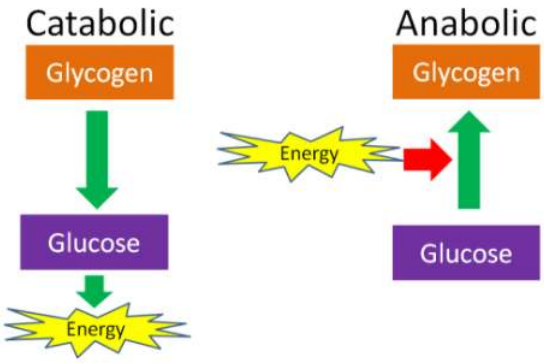


Figure 9.3 The breakdown of glycogen to glucose is catabolic. The glucose can then be used to produce energy. The synthesis of glycogen from glucose is anabolic and requires energy.3

Anabolic and catabolic can be used to describe most metabolic processes in the body. For instance, after a meal, there is often a positive energy balance, which means that there might be more energy and macronutrients available than the body needs at that time. Thus, some energy is stored and nutrients are used for synthesis, such as amino acids being used for protein or lipid synthesis. However, after a fast, or a prolonged period without energy intake, the body may go into negative energy balance which is considered catabolic. In this 'negative energy' condition, macronutrients will be mobilized from their stores to be used to generate energy. For example, if prolonged enough, muscle protein can be broken down, and some of the released amino acids can be converted into glucose to be used as an energy source.

Metabolism Takes Place within Cells

The chemical reactions involved in energy production and storage take place within the body's cells. Energy production takes place in mitochondria, whereas ribosomes help to manufacture proteins, and the smooth endoplasmic reticulum produces lipids that can

be used by other organelles.[1] Mitochondria are considered the 'powerhouse of each cell' as they generate most of the cellular energy through aerobic metabolism. Almost all body cells contain mitochondria (with the exception is the red blood cells, which produce energy anaerobically in the cytoplasm).4

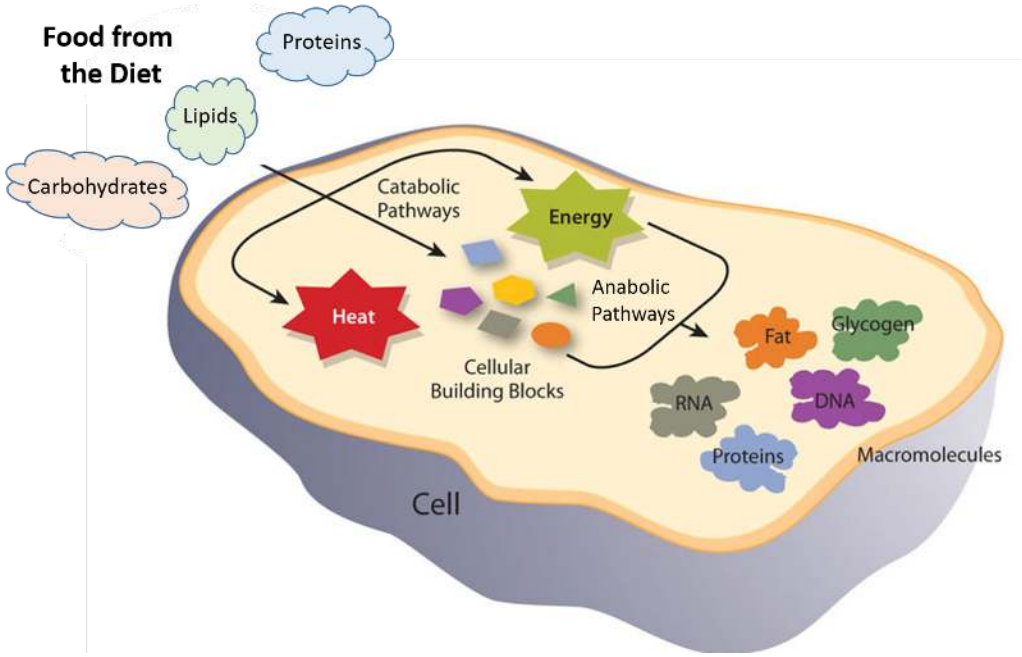


Figure 9.4. Catabolic and Anabolic Reactions. Catabolic reactions involve the breakdown of molecules into smaller components, whereas anabolic reactions build larger molecules from smaller molecules. Catabolic reactions usually release energy whereas anabolic processes usually require energy.4

The Liver Plays a Central Role in Metabolism

The most metabolically active organ in the body is the liver. In previous modules you learned that carbohydrates, fats and proteins found in in foods are digested and absorbed as monosaccharides, glycerol and fatty acids, as well as amino acids respectively. Once these nutrients have been absorbed, the liver is the first organ to metabolize them in order to send them to other tissues via the bloodstream. The liver also uses these nutrients to synthesize new compounds—for instance, converting essential amino acids into nonessential amino acids. The liver also stores some of these nutrients—glycogen, for example—to use in the future.4

Metabolism is based on (bio)chemical processes, including oxidation and reduction

A number of metabolic reactions oxidize or reduce compounds. A compound that is being **oxidized** loses at least one electron, while a compound that is **reduced** gains at least 1 electron. To remember the difference, a mnemonic device such as OIL (oxidation is lost), RIG (reduction is gained) is helpful. Oxidation-reduction reactions are illustrated in the figure below.

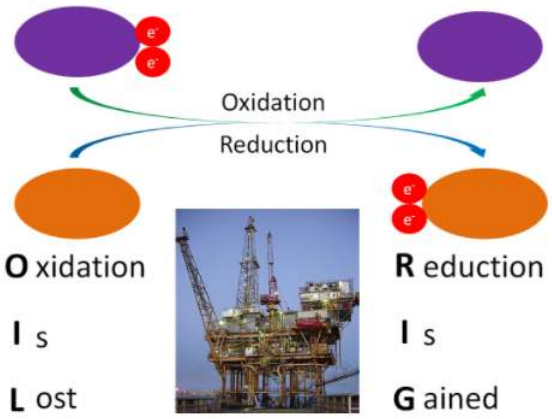


Figure 9.5 The purple compound is being oxidized, the orange compound is being reduced[1]

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

Lose **E**lections = **O**xidize

Gain **E**lections = **R**educe

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

$$Fe^{3+} + e^- \rightarrow Fe^{2+} \text{ Reduced}$$

$$Fe^{2+} \rightarrow Fe^{3+} + e^- \text{ Oxidized}$$

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

Oxidation: gains oxygen or loses hydrogen

Reduction: loses oxygen or gains hydrogen

Metabolism: aerobic vs. anaerobic pathways to generate energy

The human body is able to generate energy during times of adequate and inadequate oxygen supply. The metabolic steps to generate energy in form of 'ATP' differ in aerobic and anaerobic pathways (which will be covered in more detail later in the segment).

Important to note right now is the following:

- many catabolic reactions require adequate oxygen supply and prefer the ***aerobic pathways***
- in times of oxygen shortage, let's say you are running a 100-yard sprint, your body can provide energy to your muscles through ***anaerobic pathways***

The following Crash Course video provides an excellent introduction to Nutrition & Metabolism:



References & Attributions

1. Blake, J. S., Munoz, K. D., & Volpe, S. (2019). *Nutrition: From Science to You* (4th ed.). Pearson. [Not sure how I feel about referencing one nutrition book in another... NH]

Images

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Additional contributions made by Claudia Kelley as part of the ASCCC 2020 OERI.

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17.1.1: Cofactors and Helpers in Metabolic Reactions

Enzymes and Hormones Regulate Metabolism

The human body uses enzymes to facilitate many metabolic reactions. Several of these enzymes require cofactors to function; some textbooks refer to them as *coenzymes*. To keep things simple, we are including these coenzymes in our definition of cofactors. **Cofactors** can be either organic or inorganic molecules that are required by enzymes to function. Many organic cofactors are vitamins or molecules derived from vitamins. Most inorganic cofactors are minerals. Cofactors can be oxidized or reduced for the enzymes to catalyze the reactions.

Vitamin Cofactors - examples NAD and FAD

Two common cofactors that are derived from the B vitamins, niacin and riboflavin: they are **nicotinamide adenine dinucleotide** (NAD) and **flavin adenine dinucleotide** (FAD), respectively. The structure of NAD and FAD are shown below.

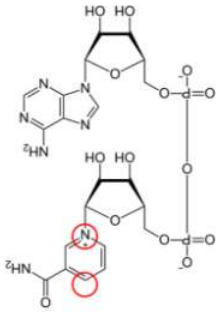


Figure 9.2.1 Structure of NAD[1] upside down. The atoms are circled to help orient this structure with Figure 9.2.3

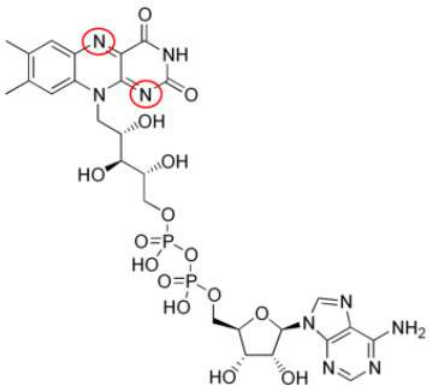


Figure 9.2.2 Structure of FAD[2]. The nitrogens are circled to help orient this structure with Figure 9.2.4

Both of these cofactors can be reduced; NAD is reduced to form NADH, while FAD is reduced to form $FADH_2$ as shown in the 2 figures below.

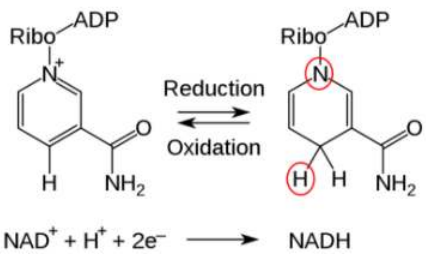


Figure 9.2.3 The reduction of NAD to form NADH[3]

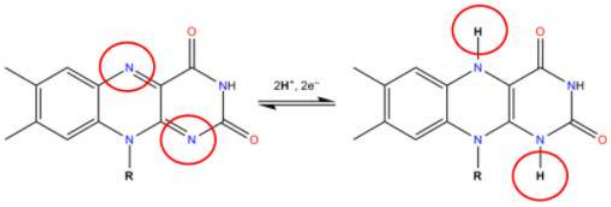


Figure 9.2.4 The reduction of FAD^4 to $FADH_2$

Accordingly, without adequate niacin and riboflavin in the diet, the coenzyme forms NAD + NAD+ and FAD would not be made in the body and metabolism would come to a stop,5 which in turn can lead to serious illness.

Mineral Cofactor - example 'iron' or Fe

An example of a mineral that serves as a cofactor is Fe^{2+} for proline and lysyl hydroxylases. We will discuss later in detail why vitamin C (ascorbic acid) is needed to reduce iron to Fe^{2+} so that it can serve as a cofactor for proline and lysyl hydroxylases.

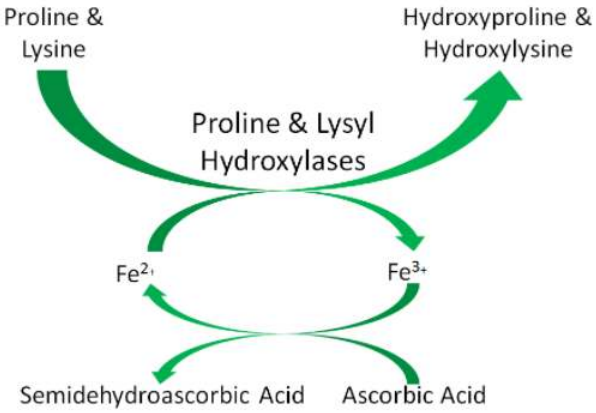


Figure 9.2.5 Iron (Fe^{2+}) is a cofactor for proline and lysyl hydroxylases

Hormones that support metabolic functions

Hormone	***Produced by***	***Type of Reaction***	***Control of Carbohydrate Metabolism***	***Control of Fat Metabolism***	***Control of Protein Metabolism***
Cortisol	Adrenal glands	Catabolic	Stimulates gluconeogenesis	In acute states, no effect. Chronically elevated levels lead to lipogenesis	Stimulates protein degradation
Epinephrine	Adrenal glands	Catabolic	Stimulates glycogenolysis	Stimulates lipolysis	May stimulate protein degradation
Glucagon	Pancreas	Catabolic	Stimulates glycogenolysis	Stimulates lipolysis	Stimulates protein degradation
Insulin	Pancreas	Anabolic	Stimulates glycogen synthesis	Stimulates lipogenesis	Stimulates protein synthesis

Table 9.2 Major Hormones with influence on metabolism (modified from5)

Check your knowledge:

True or False: Enzymes catalyze metabolic reactions with the aid of cofactors, especially forms of niacin and riboflavin, as well as hormones such as insulin, glucagon, epinephrine, and cortisol.

True or False: Insulin and glucagon are produced in the pancreas, cortisol and epinephrine are produced in the adrenal glands.

Contributors

Brian Lindshield and Claudia Kelley

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17.1.2: ATP as Fuel for Metabolism

How Does ATP Fuel Metabolism?

All body processes - starting with breathing, making your heart pump blood, digesting food, brushing teeth, walking to the bathroom or lying in bed - require energy. The more strenuous the activity, the more energy the body needs. For example, your body burns more energy to lift a 50-pound bag of dog food than to lift a 5-pound bag of flour.1

Food is the original source of fuel for all this energy to be produced by the body. However, before your body can use the energy in the piece of bread, fruit, or cereal you ate for breakfast, it must first disassemble the macronutrients, break them into smaller compounds, and transfer their energy into the high-energy molecule **adenosine triphosphate (ATP)**.

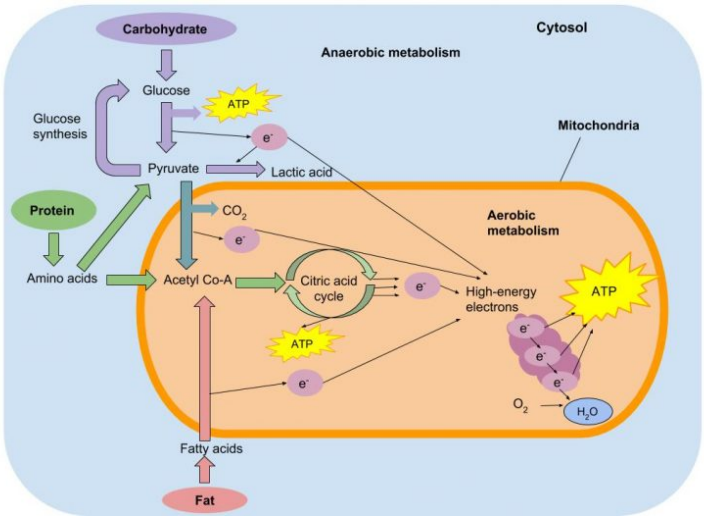


Figure 9.1.1 Anaerobic versus Aerobic Metabolism. Image by Allison Calabrese / CC BY 4.0.2

Adenosine Triphosphate Is the Cell's Energy Source

ATP is the only source of energy that cells can use directly for energy to perform any kind of work. The process of converting food to create ATP actually requires some energy (meaning, the body 'spends some ATP') to generate ATP but the net ATP production from digestion, absorption, and energy conversion is far greater than the 'initial ATP expense'.

ATP has three components: adenine, a nitrogen-containing compound; ribose, a five-carbon sugar; and three phosphate groups (which contain phosphorus and oxygen). The energy in ATP is stored in the bonds that connect the phosphate groups to each other. As *Figure 9.1.2* illustrates, when the body needs energy, one of the phosphate group bonds is hydrolyzed. This releases one phosphate molecule plus a tremendous amount of energy. The new molecule that is formed is called adenosine diphosphate (ADP). At any given moment, cells only have 3–5 seconds' worth of ATP available for immediate use; therefore, the body must continually produce ATP to provide a constant supply of energy.1

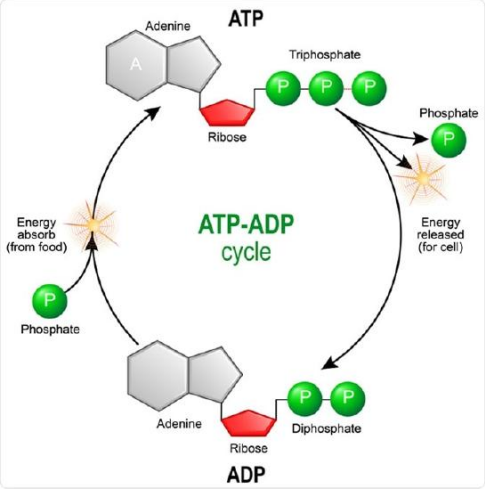


Figure 9.1.2 ATP ADP cycle. Adenosine triphosphate (ATP) is an organic chemical that provides energy for intracellular energy transfer. Adenosine diphosphate (ADP) is organic compound for metabolism in cells. Illustration Credit: Designua / Shutterstock3

Just to give you an idea: the oxidation of 1 glucose molecule generates up to 38 APT molecules.4

Important to remember: ATP is the energy source cells use to fuel metabolic reactions. Cells only have 3–5 seconds' worth of ATP; thus, ATP must be regenerated from ADP and phosphate (which can be donated by creatine phosphate) or produced during anaerobic metabolism, which can fuel the body for no more than 1.5 minutes, or aerobic metabolism, which can continue indefinitely.1

We will review each in the upcoming segments.

Check your knowledge:

True or False: Cells use ATP to provide energy for metabolic reactions.

True or False: ATP must be regenerated from ADP and phosphate (which can be donated by creatine phosphate) or produced during anaerobic metabolism, which can fuel the body for no more than 1.5 minutes, or aerobic metabolism, which can continue indefinitely.

Contributors

Claudia Kelley

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17.1.3: How Do the Macronutrients Provide ATP?

Major metabolic pathways that macronutrients follow to produce ATP.

After the energy-containing nutrients have been absorbed through the small intestine, they can enter a metabolic pathway and be converted to energy or be stored as fat for later use. These three macronutrients —carbohydrates, proteins, and fats— fuel the production of ATP by entering the pathway at some point in the stages of energy metabolism. Their fate is determined by the chemical reactions within each metabolic pathway (see figure 9.1.3.1). The major energy nutrient, which is ***glucose***, fuels metabolism from the first stage through the final stage.[1] As you learned in the previous segments, several amino acids can be converted into glucose and fats (or better 'triglycerides') are broken down into fatty acids and glycerol, which then contribute to energy generation as they are transformed into different substrates along the pathway.

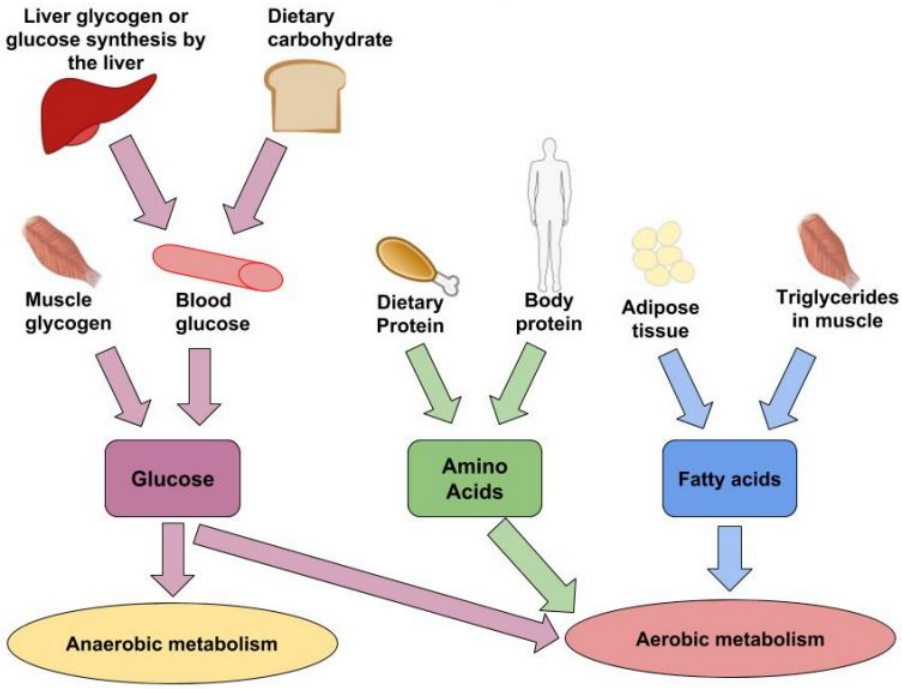


Figure 9.1.3.1 Fuel Sources for Anaerobic and Aerobic Metabolism, and metabolic fate of the three energy-containing macronutrients: carbohydrates, proteins, and fats.[2]

Please remember from section 9.1, figure 9.1 that food is converted into cellular energy as ATP in three stages:

- Stage 1 of the metabolic fate of food includes glucose, glucogenic amino acids and glycerol to enter the anaerobic pathway glycolysis pathway to produce pyruvate.
- Stage 2 of the energy pathway includes the conversion of glucose, ketogenic amino acids and fatty acids to be converted into Acetyl-CoA.
- In stage 3 of the energy pathway, Acetyl-CoA enters into the Krebs Cycle (which then leads to the Electron Transport Chain to generate ATP).

Carbohydrates are unique in that they are oxidized anaerobically in stages 1 and 2 of metabolism and also aerobically in stage 3. Fatty acids derived from triglycerides are only oxidized aerobically in stage 2; this process is slower than anaerobic metabolism and hence only executed when enough oxygen is available. The fatty acids are split from the glycerol backbone before they are metabolized and converted to acetyl CoA, whereas glycerol enters metabolism through glycolysis.[1]

When amino acids from proteins are needed for energy, the structure of their side group determines where they enter the metabolic pathway: glucogenic amino acids can be transformed into glucose through ***gluconeogenesis*** when carbohydrate intake is low. They can also be converted to substrates and enter glycolysis in stage 1. ***Ketogenic amino acids*** (keto=ketone, genic=forming) can be converted to acetyl CoA in stage 2, while a few other amino acids can be converted to intermediate substrates in the Krebs Cycle in stage 3.[1]

Definition: *ketogenic* -- molecules that can be transformed into ketone bodies.[1]

In the next segment, we are looking at the transformation of glucose to pyruvate during ***glycolysis*** .

Check your knowledge:

True or False: Glucogenic amino acids, glycogen, and glycerol can enter into anaerobic glycolysis at specific pathways to produce pyruvate.

True or False: Cells use ATP to provide energy for metabolic reactions.

Contributors

Claudia Kelley

References & Links

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17.1.4: Central Aspect of Generating Pyruvate in Energy Metabolism - Glycolysis up close

Glycolysis Transforms Glucose to Pyruvate

The first step in forming ATP from glucose is **glycolysis** (glyco=glucose,lysis=break apart), the universal pathway for glucose oxidation. Glucose metabolism is an essential energy source for all cells and particularly the brain and red blood cells. As you follow the metabolic pathway illustrated in *figure **9.1.4.1***, track the carbons through the process from beginning to end.

Definition: *glycolysis* -- *b*reakdown of glucose; for each molecule of glucose, two molecules of pyruvate and two ATP molecules are produced.[1]



Figure 17.1.4.1: Copy and Paste Caption here. (Copyright; author via source)

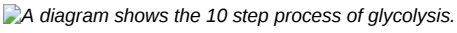


Figure ***9.1.4.1.*** Glycolysis is a 10-step process that takes place in the cytoplasm of the cell; it converts glucose to pyruvate. Notice that glucose is depicted here as a row of six carbons, rather than a six-sided ring structure as this representation makes it easier to see the movement of carbon during metabolism.[1]

Conversion of Glucose to Pyruvate

Glycolysis is a 10-step anaerobic catabolic pathway that takes place in the cytoplasm of the cells. It begins with one six-carbon glucose molecule and ends with two three-carbon molecules of **pyruvate** and a net of two molecules of ATP.[2]

Definition: pyruvate -- **Three-carbon molecule formed from the oxidation of glucose during glycolysis.**

The initial step of glycolysis requires the use of ATP; in this reaction, one phosphate molecule is transferred from ATP to the sixth carbon of the glucose molecules, which generates glucose 6-phosphate and ADP. Once glucose 6-phosphate is formed, it continues through nine more reactions until the anaerobic stage of glycolysis is complete and pyruvate is created (see **Figure 9.1.4.1**).

After completing the ten steps, glycolysis produces 2 molecules of ATP and 2 molecules of pyruvate; additionally, glycolysis generates hydrogen ions (H+). As you can see in **Figure 9.1.4.1**, step 6, the coenzyme NAD+ picks up a hydrogen ion and reduces NAD+ to NADH. The NADH eventually carries the hydrogen ion to the final stage of energy production, the electron transport chain.

Notice that the coenzyme form of riboflavin, FAD, plays no role in glycolysis. FAD is reduced to FADH2 in the Krebs Cycle. Like NADH, FADH2 carries its hydrogen ion to the electron transport chain. There, the hydrogen ions are used to produce ATP from ADP.[2]

Metabolism of Fructose and Galactose

In addition to glucose, other monosaccharides, including fructose and galactose, can be used to produce ATP, but they are converted to substrates in glycolysis at different points. In muscle, fructose is first phosphorylated before it enters glycolysis as fructose 6-phosphate (see step 3 in **Figure 9.1.4.1**). In the liver, however, fructose passes through a more complex conversion before it becomes a substrate in glycolysis. It is first phosphorylated to form fructose 1-phosphate, which is then split into glyceraldehyde and dihydroxyacetone phosphate (DHAP), and then enters glycolysis as glyceraldehyde 3-phosphate (see steps 4 and 5 in **Figure 9.1.4.1**).[1]

Galactose is also metabolized in the liver and must be converted to glucose before it can enter glycolysis. The first step is to add a phosphate to galactose to produce galactose 1-phosphate. After four more metabolic steps, galactose enters glycolysis as glucose 6-phosphate (see step 1 in **Figure 9.1.4.1**).[1]

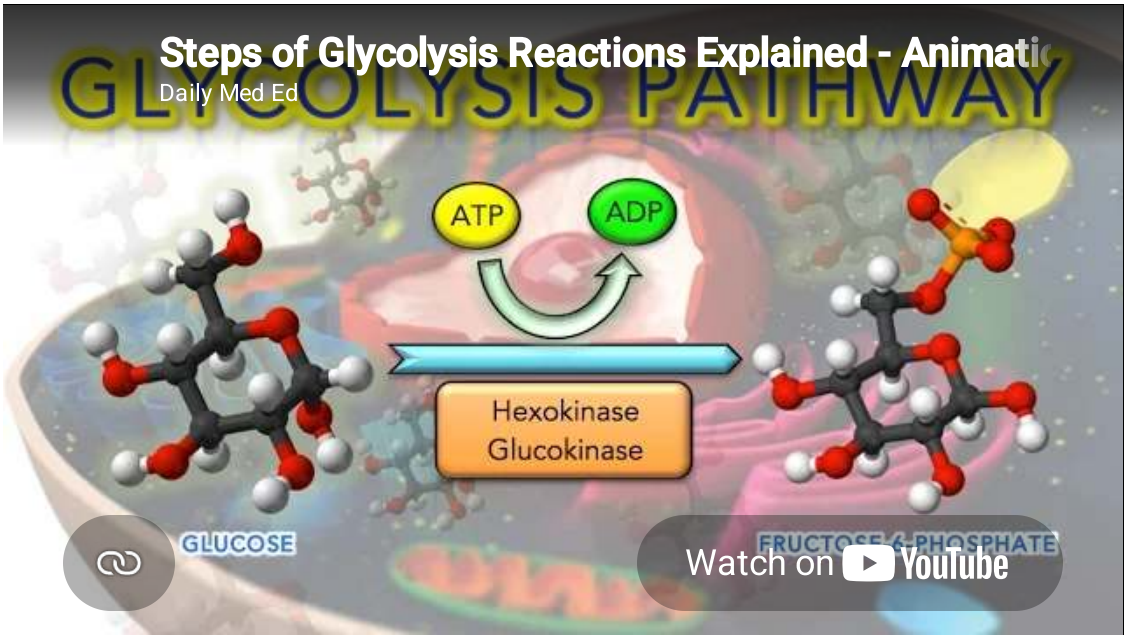
A specific enzyme directs each step of converting each monosaccharide into an intermediate substrate in glycolysis. Although rare, deficiencies in any of these enzymes due to genetic mutations have a debilitating effect on metabolism. For example, a deficiency in the enzyme that converts galactose into glucose results in a condition known as *galactosemia*, which can lead to mental retardation and liver damage unless dietary intake of galactose is controlled.[1]

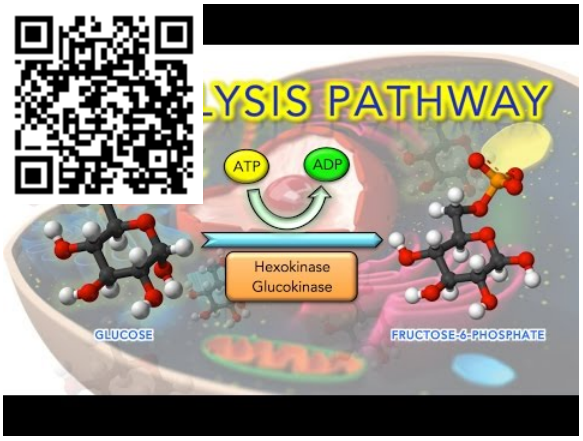
Amino Acids and Glycerol Can Yield Pyruvate

Pyruvate sits at the junction between several significant pathways in energy metabolism. Pyruvate is the end product for anaerobic glycolysis and the beginning molecule for gluconeogenesis. It can be converted to acetyl CoA and enter the Krebs cycle or provide the basis for long-chain fatty acids to be stored in the adipose tissue as a triglyceride. In other words, pyruvate serves as an intermediate substrate that helps balance the energy needs of the cells.[1]

Video Animation

If the above was 'too techy' for you, please watch this short video:





Check your knowledge:

True or False: In the cytoplasm of the cell, glycolysis is a 10-step anaerobic catabolic pathway that begins with one six-carbon glucose molecule and ends with two three-carbon molecules of pyruvate and a net of two molecules of ATP.

True or False: Pyruvate is a three-carbon molecule formed from the oxidation of glucose during glycolysis.

Contributors

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17.2: Energy Systems

Learning Objectives

- Distinguish between the major energy pathways in the human body.

Introduction

Generating energy for life-sustaining and health-promoting processes is a dynamic process. Humans obtain energy through consuming a healthy, well-balanced diet. The ingested macronutrients —carbohydrates, fats, and proteins— are ultimately broken down in order to release the stored energy. Please recall: 1 g of carbohydrates or protein provides 4 kcal, whereas 1 g of fat provides 9 kcal.1

The energy can be used in different processes, such as building muscle mass, repairing muscle damage, active transport of many substances across cell membranes (e.g., sodium and potassium), as well as for mechanical energy, muscle action and, consequently, human movement. However, for all these processes to occur, the chemical energy released must be stored in the form of adenosine triphosphate (ATP).

Inside of the ATP molecule, the bonds that link the two phosphates together represent high-energy bonds because they release considerable useable energy: approximately 7.3 Kcal per molecule of ATP.2 In the specific case of muscle contraction, the myosin head contains a binding site for the molecule of ATP; the adenosine triphosphatase (ATPase), located here, splits the ATP to yield adenosine diphosphate (ADP), inorganic phosphate (Pi), and most importantly, energy.2 Therefore, ATP is the first energy source of mechanical muscle contraction processes.

However, cells can store only limited amounts of ATP: the human body only stores about 80-100 g of ATP at any given time under normal resting conditions.2 This implies that the body must be constantly generating new ATP to provide energy for all cellular ATP-dependent processes, including muscle contraction.

The human body can generate ATP through three different metabolic pathways -- depending on the immediate energy need and oxygen availability, the body produces ATP through:

1. ATP-CPr pathway
2. the glycolytic pathway
3. the oxidative system

From the three energy metabolic pathways, the first two can function in the absence of oxygen, and therefore are considered part of the ***anaerobic metabolism***.
The last system requires the presence of oxygen and is therefore considered part of ***aerobic metabolism***. The oxidative system comprises both carbohydrates and fat oxidation.2



Phosphagen System

Although the most economical way for our bodies is to produce ATP under aerobic conditions through glycolysis or fat oxidation, these processes take time and require oxygen. So, when 'time' is of the essence and oxygen might be in short supply (e.g., you are attempting to escape a lion attack or are running a sprint), the body can use the ATP-Phosphocreatine (PCr) system to quickly restore at least some ATP from ADP.

The ATP-PCr pathway is an anaerobic energy system in which the generation of ATP is coupled with the exergonic (energy-releasing) breakdown of phosphocreatine stored in muscle cells. The breakdown frees inorganic phosphate, which then combines with ADP to form ATP. The ATP-PCr system is the **quickest source of ATP** for muscle actions. Athletes in power events lasting up to 10 s (e.g. 100 m sprints) derive most of their ATP from this system.4

Figure 9.2.1. In the ATP-PCr system, the energy liberated from the hydrolysis of phosphocreatine (PCr) is used to synthesized adenosine triphosphate (ATP) via the binding of inorganic phosphate (Pi) to adenosine phosphate (ADP).5

In order to regenerate ATP from ADP a phosphate source is required. As illustrated in Figure 9.2.1, the phosphate produced from the initial breakdown of ATP can be a source. Another source of phosphate is creatine phosphate (PCr), also called phosphocreatine. PCr is a high-energy compound formed in muscle cells when creatine (a nitrogenous organic acid found in foods and produced in the body) combines with phosphate. This phosphate can be released from creatine phosphate and added to ADP to form ATP. In addition, when the phosphate bond is broken, energy is released, which provides the fuel needed to restore ATP. These two sources of phosphate, ATP and PCr, can provide enough ATP to sustain a sprint for about 10 seconds.6

What happens next?

As the available ATP dwindles and creatine phosphate in the muscle cell is exhausted, the body relies on anaerobic and aerobic metabolism to produce the needed ATP. Although anaerobic metabolism produces more ATP per minute than aerobic metabolism, it is very limited in its use (it only provides about 1–1.5 minutes of maximal activity).6

Activities that primarily involve anaerobic metabolism are high-intensity, short-duration activities such as sprinting or heavy weightlifting. When the demand for ATP is greater than the rate at which metabolism can produce it, the activity slows down or may stop completely. This is one reason why individuals who lift weights have to rest between sets; it gives the body time to form more ATP to be used for the next set of lifts.

Aerobic metabolism produces less ATP per minute than anaerobic metabolism, but it can continue indefinitely. Low-intensity, long-duration activities, such as walking or slow jogging, primarily involve aerobic metabolism. The transformations that convert energy stored in carbohydrates, proteins, and fats into ATP are tightly integrated and somewhat complex. To learn this material, we break down these integrated processes by stages.6

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1. Gropper SS, Smith JL, Groff JL. (2016) Advanced nutrition and human metabolism (7th ed.). Cengage.
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Additional contributions made by Claudia Kelley as part of the ASCCC 2020 OERI.

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17.2.1: Short-Term Energy- Glycolytic Pathway

The Glycolytic System fuels Short-Term Energy demands

After the immediate source of cell energy, including that used for muscle contraction (ATP and PCr) have reached exhaustion, the next more complex process begins to take action within the cytosol. The **glycolytic pathway** breaks down carbohydrate storage forms of glycogen and glucose.[1]

In a series of 10-12 enzymatic reactions, glucose is broken down in the process called **glycolysis** to produce two molecules of pyruvate and four molecules of ATP. However, as mentioned earlier, the initial process is ATP-dependent and requires two molecules of ATP to 'jump-start' the breakdown of glucose. Hence, the net generation of ATP during the initial glycolysis step is (-2) + 4 = two molecules of ATP.[2]

Glossary Term: Glycolysis - Breakdown of glucose; for each molecule of glucose, two molecules of pyruvate and two ATP molecules are produced.

Glycolysis (g l y c o = glucose , l y s i s = break apart) is the universal pathway for glucose oxidation, whereby glucose metabolism is an essential energy source for all cells and particularly the brain and red blood cells, as well as skeletal muscles.[3]

In contrast, if glycogen is broken down to pyruvate during **glycogenolysis**, only one ATP molecule is consumed, and therefore glycogenolysis allows for a higher ATP harvest as three ATP molecules are generated.[1] In both cases, the amount of energy produced is relatively small, and the available capacity of this system is ~1 min (see figure 9.2.2.1). In the absence of adequate oxygen (e.g, during a 100-yard sprint), pyruvate (a.k.a. pyruvic acid) is then converted to lactic acid; the detailed transition reaction is described in segment 9.3.5.

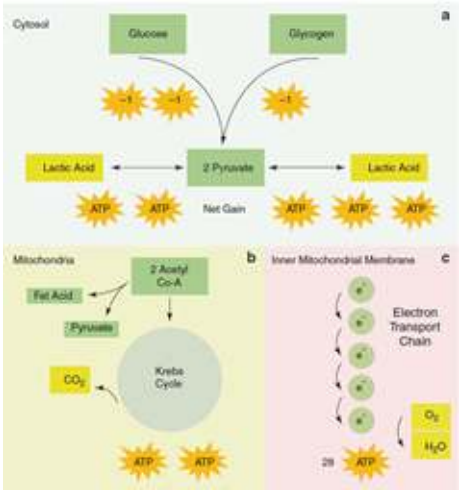


*Figure 9.2.2.1 The production of ATP starts during glycolysis or glycogenolysis with the formation of pyruvate (**a**), which is further broken down into acetyl coenzyme A (which may also be used to form a fatty acid or pyruvate) to enter the Krebs cycle (b). The hydrogen ions released in this reaction are carried to the electron transport chain where a large amount of ATP is formed (c). [Adopted and modified from 1]*

The glycolytic pathway is regulated by negative feedback; meaning, it is upregulated by high concentrations of ADP and Pi whereas it is downregulated by high concentrations of ATP.[2]

For more detail on glycolysis and glycogenolysis, please refer to sections 9.3.3. and 9.3.4.

Although the amount of ATP produced during glycolysis and glycogenolysis is relatively scarce, the combined actions of both the ATP-PCr and glycolytic systems allow the skeletal muscles to generate force when oxygen availability is low.

If sufficient oxygen is available to the muscle cell during glycolysis, the oxidative system begins to assume the majority of energy production.[1]

Check your knowledge:

True or False: The net energy gain from glycolysis is 2 molecules of ATP.

Contributors

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1. Sousa, A., Ribeiro, J. & Figueiredo, P. (2019). Physiological Demands in Sports Practice. 10.1007/978-3-030-10433-7_4.
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17.2.2: Long-Term Energy- Oxidative System

The Oxidative System

At rest and when adequate oxygen is available to cells during glycolysis, the oxidative system makes up the bulk of energy production in the human body. The same holds true for intense exercise lasting more than 2 h after glycogen stores have been depleted; in which case the body switches to fats (lipids) as the primary source of energy.[1]

Please recall that dietary fats contain 9 kcal/g and therefore contribute immensely to energy metabolism in the human body; due to the almost endless reserve capacity in adipose tissue, the supply of fatty acids for energy production is virtually unlimited. In order to be used for energy in the oxidative system however, free fatty acid must be converted into acetyl Co-A (during a process called β-oxidation; please refer to segment 9.4.2 for detail).

Regardless of the energy source used, oxidation starts in the mitochondria after acetyl coenzyme-A (acetyl CoA) has been formed, and initiates a complex series of chemical reactions that allows complete oxidation of Acetyl-CoA in the Krebs cycle (also known as a citric acid cycle or tricyclic acid cycle [TCA cycle]; see Fig. 9.2.3.1 b).

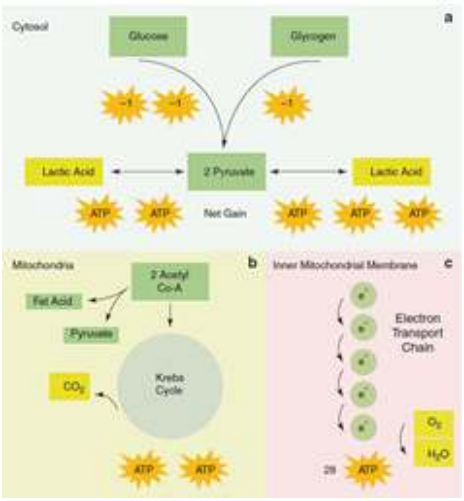


*Figure 9.2.3.1 The production of ATP starts during glycolysis or glycogenolysis with the formation of pyruvate (**a**), which is further broken down into acetyl coenzyme A (which may also be used to form a fatty acid or pyruvate) to enter the Krebs cycle (b). The hydrogen ions released in this reaction are carried to the electron transport chain where a large amount of ATP is formed (c). [Adopted and modified from 1]*

The Krebs Cycle Releases High-Energy Electrons

Krebs cycle, also known as tricarboxylic acid (TCA) cycle or citric acid cycle, is regulated by negative feedback. Similar to the glycolytic pathway, it is upregulated by high concentrations of ADP and Pi whereas it is downregulated by high concentrations of ATP.[2]

The Krebs cycle is the third stage of energy metabolism. It results in the full oxidation of acetyl CoA (Figure 9.2.3.2) and occurs in the mitochondria. Up to this point, the individual macronutrients have followed different metabolic routes and entered the energy pathway at different points;[3] now, they have all arrived at acetyl CoA.

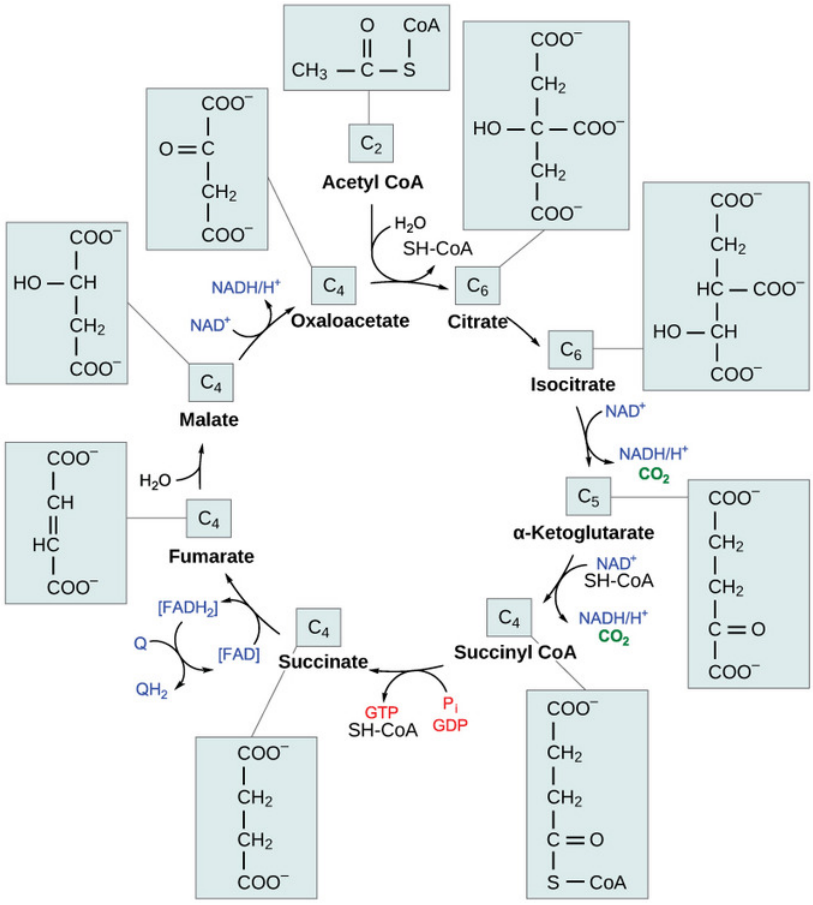


Figure 9.2.3.2 ***The Krebs or citric acid cycle****: after conversion of pyruvate to acetyl CoA, the acetyl group from acetyl CoA is attached to a four-carbon oxaloacetate molecule to form a six-carbon citrate molecule. Through a series of steps, citrate is oxidized, releasing two carbon dioxide molecules for each acetyl group fed into the cycle. In the process, three NAD+ molecules are reduced to NADH, one FAD molecule is reduced to FADH2, and one ATP or GTP (depending on the cell type) is produced (by substrate-level phosphorylation). Because the final product of the citric acid cycle is also the first reactant, the cycle runs continuously in the presence of sufficient reactants.*[4]

Recall that energy source molecules are carbon-containing compounds that can be oxidized or lose electrons; during each turn of the Krebs cycle, hydrogen ions, which carry high-energy electrons, are released and gathered up by NAD + , which then forms NADH + H^+, and by FAD, which then forms $FADH_2$. These electron carriers release their 'charge' in the electron transport chain (which is discussed in segment 9.3.7). In total, for each turn of the Krebs cycle, four coenzymes are reduced, along with the formation of carbon dioxide (CO2).[3]

Key Points in the Krebs Cycle

- The four-carbon molecule, oxaloacetate, that began the cycle is regenerated after the eight steps of the Krebs cycle.
- The eight steps of the Krebs cycle are a series of redox, dehydration, hydration, and decarboxylation reactions.
- Each turn of the cycle forms one GTP or ATP as well as three NADH molecules and one $FADH_2$ molecule, which will be used in further steps of cellular respiration to produce ATP for the cell.

In summary, the Krebs cycle process will generate CO2 and 2 molecules of ATP.[2] For more detailed biochemical information on the Krebs or Citric Acid Cycle, please see segment 9.3.6.

As the generated NADH and $FADH_2$ molecules enter the Electron Transport Chain (see Fig. 9.2.3.1 c, and refer to segment 9.3.7 for detail), an additional 28 APT molecules are generated for a total harvest of 32-34 ATP molecule per molecule of glucose.[2]

Check your knowledge:

True or False: Glucose, fats and proteins can be converted into Acetyl-CoA to enter the Krebs cycle and later the electron transport chain pathways to generate energy.

Contributors

Claudia Kelley

References & Links

1. Sousa, A., Ribeiro, J. & Figueiredo, P. (2019). Physiological Demands in Sports Practice. 10.1007/978-3-030-10433-7_4.
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17.3: Carbohydrate Metabolism

Learning Objectives

- Review carbohydrate metabolism.

Introduction

There are many metabolic pathways, processes, or reactions that are involved in the synthesis or degradation of carbohydrates and compounds formed from them. Please note that most of these pathways are not specific to carbohydrates only. For example, in gluconeogenesis certain (glucogenic) amino acids are used for synthesizing glucose if needed.

Overview of Terminology

- **Glycogenesis**
  - glycogen synthesis
- **Glycogenolysis**
  - glycogen breakdown
- **Gluconeogenesis**
  - synthesis of glucose from a non-carbohydrate source
- **Glycolysis**
  - breakdown of glucose to pyruvate
- **Transition Reaction**
  - conversion of pyruvate to acetyl-CoA
- **Krebs Cycle (also known as Citric Acid or Tricarboxylic acid (TCA) Cycle)**
  - acetyl-CoA combines with oxaloacetate to form citrate; ATP, NADH, and $FADH_2$ are produced in the cycle
- **Electron Transport Chain**
  - oxidative phosphorylation, producing ATP from NADH and $FADH_2$

References & Attributions

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17.3.1: Glycolysis

If a person is in a catabolic state or in need of energy, such as during fasting, glucose will be used for glycolysis.

Glycolysis is the metabolic process of breaking down of one glucose molecule (6 carbons) into two pyruvate molecules (3 carbons). During this process, a net of two ATPs and two NADHs are also produced.

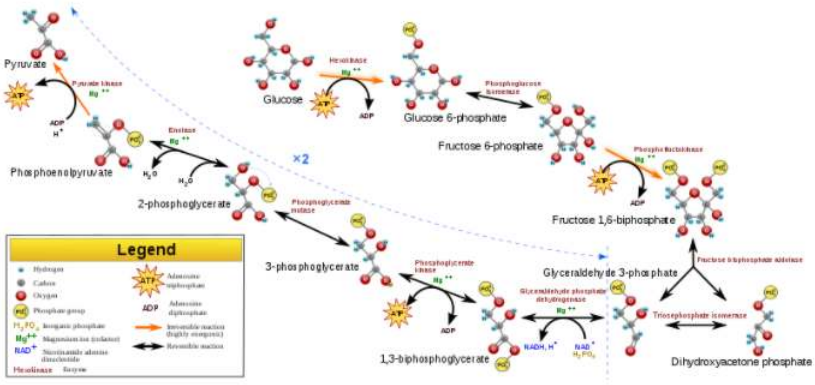


Figure 9.3.4.1 Glycolysis[1]

3 steps of Glycolysis

1. Energy investment step - 2 ATP are added to the 6 carbon molecule.

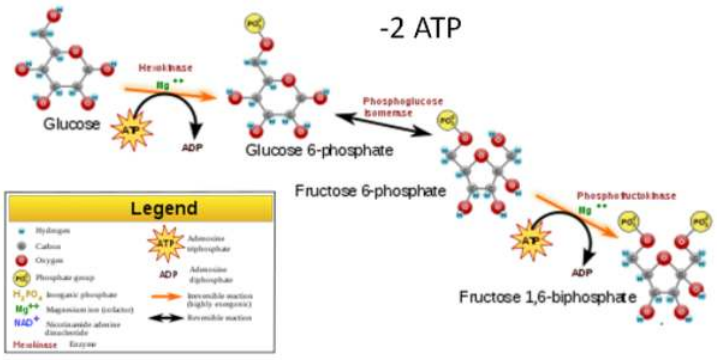


Figure 9.3.4.2 Glycolysis step 1, energy investment[1]

2. Glucose Split - The 6 carbon molecule is split into two 3 carbon molecules.

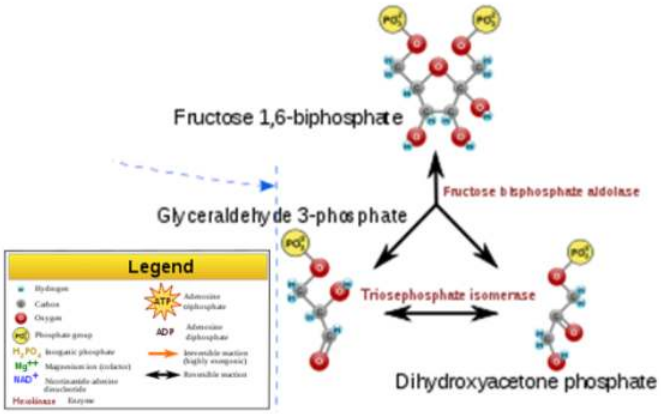


Figure 9.3.4.3 Glycolysis step 2, glucose split[1]

3. Energy harvesting step - 1 NADH and 2 ATPs are produced from each 3 carbon molecule (there are two 3 carbon molecules formed from each glucose).

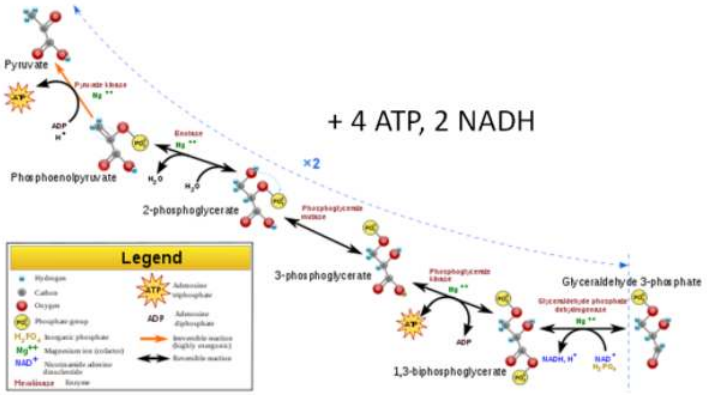


Figure 9.3.4.4 Glycolysis step 3, energy harvesting[1]

Thus, from a molecule of glucose, the harvesting step produces a total of four ATPs and two NADHs. Subtracting the harvesting from the investment step, the net output from one molecule of glucose is two ATPs and two NADHs.[3]

The figure below shows the stages of glycolysis, as well as the transition reaction, citric acid cycle, and electron transport chain that are utilized by cells to produce energy. They are also the focus of the next 3 sections.

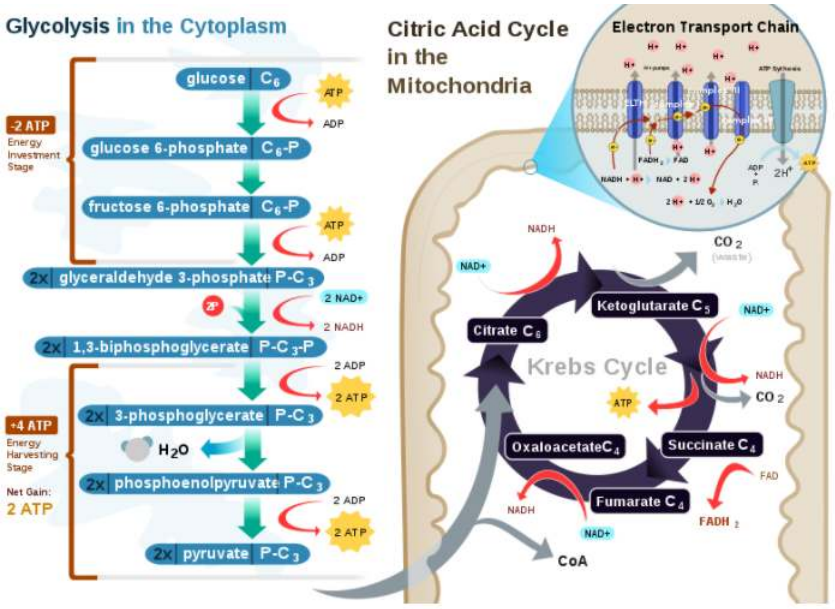
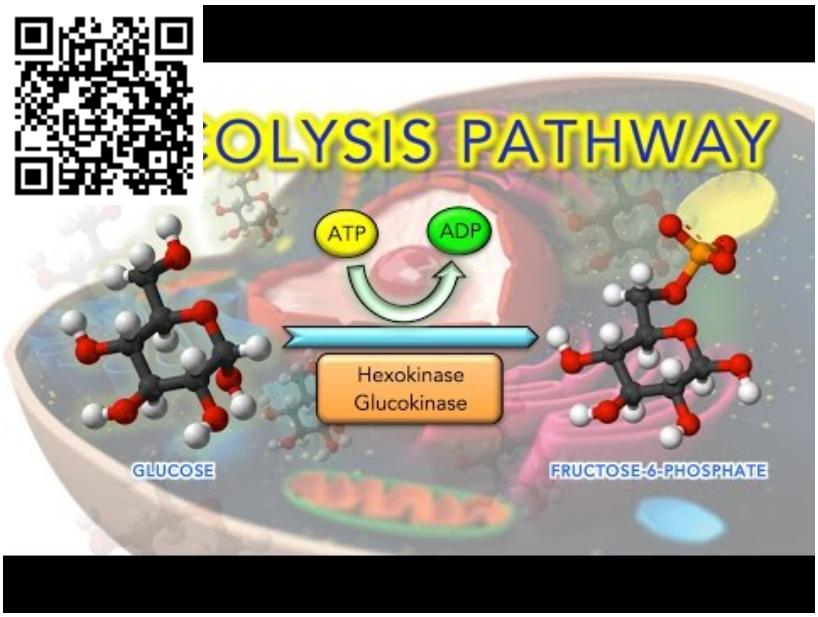


Figure 9.3.4.5 Glycolysis, transition reaction, citric acid cycle, and the electron transport chain[2]

Video Animation

If the above was 'too techy' for you, please watch this short video:



Contributors

Brian Lindshield and Claudia Kelley

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Links

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17.3.2: Transition Reaction from Pyruvate into Acetyl CoA (keep!)

Pyruvate is transformed into Acetyl CoA

Glycolysis began with the entry of one six-carbon molecule of glucose that now produced two three-carbon molecules of pyruvate, with a net gain of two ATP molecules, two coenzyme molecules in the form of NADH, two hydrogen ions (which enter the electron transport chain), and two molecules of water.

In the following metabolic pathway the newly formed pyruvate as it is transformed into **acetyl CoA**.

Glossary entry: acetyl CoA - **Two-carbon compound formed when pantothenic acid combines with acetate.**

Acetyl CoA is often called the "gateway" molecule for aerobic metabolism because all energy-producing nutrients—glucose, amino acids, fatty acids, glycerol, even alcohol—are usually transformed to acetyl CoA before entering the so-called tricarboxylic acid cycle (a.k.a. TCA cycle). Until this point along the metabolic pathway, energy is produced anaerobically. When cells contain an ample supply of oxygen, pyruvate now continues down the aerobic energy pathway to create acetyl CoA.[1]

In the presence of oxygen, the two molecules of pyruvate formed during glycolysis cross the outer mitochondrial membrane and enter the mitochondria, where they each lose a carbon. Next, coenzyme A, an organic compound synthesized from the B vitamin pantothenic acid, attaches to the remaining two carbons from each pyruvate molecule to form acetyl CoA (see figure 9.3.5.1). Thus a three-carbon pyruvate molecule is changed into a two-carbon acetyl CoA. The third carbon combines with oxygen to form carbon dioxide and is expelled through the lungs as waste.[1]

Accordingly, if a person is in a **catabolic state** or needs energy, the way how pyruvate will be used depends on whether adequate oxygen levels are present. If there are adequate oxygen levels (aerobic conditions), pyruvate moves from the cytoplasm, into the mitochondria, and then undergoes the transition reaction. If there are inadequate oxygen levels (anaerobic conditions), pyruvate will instead be used to produce lactate in the cytoplasm.

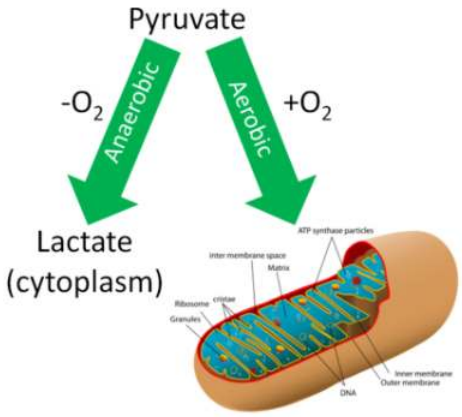


Figure 9.3.5.1 Pyruvate fork in the road. What happens depends on whether it is aerobic or anaerobic respiration[2]

The transition reaction is the gateway transition between glycolysis and the citric acid cycle. The **transition reaction converts pyruvate (3 carbons) to acetyl CoA (2 carbons)** while producing carbon dioxide (CO_2) and NADH as shown in figure 9.3.5.2 below. Figure 9.3.5.2 illustrates the transition reaction that combines pyruvate with CoA and NAD entering to produce acetyl-CoA, CO_2, and NADH.

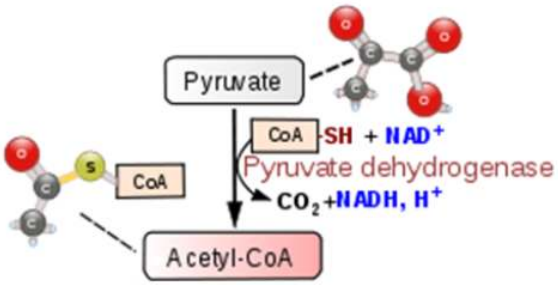


Figure 9.3.5.2*Transition reaction*[3]

Thus, the transition reaction produces 2 acetyl-CoAs, 2 molecules of CO_2, and 2 NADHs from one molecule of glucose!

Contributors

Brian Lindshield and Claudia Kelley

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17.3.3: Electron Transport Chain (keep!)

The Electron Transport Chain and Oxidative Phosphorylation Produce the Majority of ATP

We reviewed the three Energy Systems in section 9.2., where you learned about the ATP-PCr energy pathway, the glycolytic pathway, as well as the oxidative system that involves the Krebs Cycle, but also the electron transport chain (ETC) to covert the harvested energy molecules into ATP. Please recall from figure *Figure 9.2.3.1* that the production of ATP starts during glycolysis or glycogenolysis with the formation of pyruvate, which is further broken down into acetyl coenzyme A to enter the Krebs cycle. The hydrogen ions released in this reaction are carried to the ETC where a large amounts of ATP molecules are formed.

The Electron Transport Chain as major ATP generator

The electron transport chain is composed of a series of protein complexes located in the inner mitochondrial membrane that function as electron carriers (Figure 9.3.2.1). The high-energy electrons delivered to the electron transport chain by NADH + H and $FADH_2$ are passed from one protein complex to the next. As the electrons are passed along the chain, hydrogen ions are pumped out of the mitochondrial matrix into the intermembrane space. The hydrogen ions accumulate, creating a high concentration gradient that forces them back across the mitochondrial membrane into the matrix. There, the enzyme ATP synthase uses the energy generated by the concentration gradient to add a phosphate to ADP, forming ATP through a process called oxidative phosphorylation. At the same time, oxygen, electrons, and hydrogen ions combine to form water. The ATP produced flows into the cytoplasm to be used by the body.[1]

Definition: ***Electron Transport Chain*** - final stage of energy metabolism in which NADH and $FADH_2$ transport high-energy electrons to the protein complexes resulting in the formation of ATP and water.

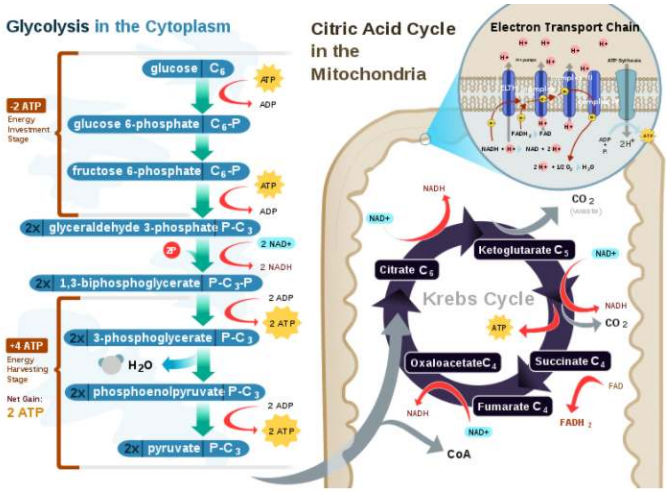


Figure 9.3.2.1 The pathways involved in aerobic respiration[2]

The **electron transport chain** contains a number of electron carriers. These carriers take the electrons from NADH and $FADH_2$, pass them down the chain of complexes and electron carriers, and ultimately produce ATP. More specifically, the electron transport chain takes the energy from the electrons on NADH and $FADH_2$ to pump protons (H^+) into the intermembrane space. This creates a proton gradient between the intermembrane space (high) and the matrix (low) of the mitochondria. ATP synthase uses the energy from this gradient to synthesize ATP. Oxygen is required for this process because it serves as the final electron acceptor, forming water. Collectively this process is known as oxidative phosphorylation. The following figure and animation do a nice job of illustrating how the electron transport chain functions.

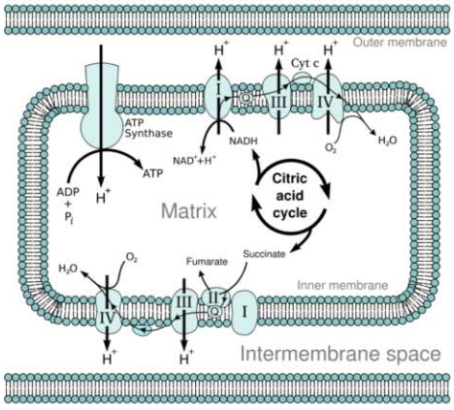


Figure 9.3.2.2 Location of the electron transport chain in the mitochondria[3]

Energy Harvesting Results

In the ETC, 2.5 ATP/NADH and 1.5 ATP/$FADH_2$ are produced (some resources will say 3 ATP/NADH and 2 ATP/$FADH_2$).

Notice that the vast majority of ATP is generated by the electron transport chain. If we do the math, 28/32 X 100 = 87.5% of the ATP from a molecule of glucose is generated by the electron transport chain. Remember that this is aerobic and requires oxygen to be the final electron acceptor. If 3 ATP/NADH and 2 ATP/$FADH_2$ are used instead of 2.5 ATP/NADH and 1.5 ATP/$FADH_2$ that were used above, total ATP and percentage of ATP produced by the electron transport chain would be different. But the takeaway message remains the same. The electron transport chain by far produces the most ATP from one molecule of glucose.

Glycolysis: 2 NADH

Transition Reaction: 2 NADH

Krebs Cycle: 6 NADH, 2 $FADH_2$

Total 10 NADH, 2 $FADH_2$

Multiply that by the amount of ATP per NADH or FADH2 to yield:

10 NADH X 2.5 ATP/NADH = 25 ATP

2 $FADH_2$ X 1.5 ATP/$FADH_2$ = 3 ATP

Total 28 ATP

Therefore under consideration of the preceding pathways, **one molecule of glucose** produces:

Metabolic Pathway	**ATP Generated**	**NADH Generated**	**$FADH_2$ Generated**
Glycolysis	2	2	
Transition Reaction		2	
Krebs Acid Cycle	2	6	2
Electron Transport Chain	28		
Total '	**32**		

Putting it together video

If you are an audio-visual learner, please watch this 13 minute Crash Course on the Krebs Cycle and the Electron Transport Chain



For additional videos, look at

- Electron Transport Chain - http://www.youtube.com/watch?v=1engJ...eature=related
- Oxidate it or Love it/Electron to the Next One - http://www.youtube.com/watch?v=VCpNk...response_watch

Check your knowledge:

True or False:

Contributors

Brian Lindshield and Claudia Kelley

References & Links

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2. http://en.Wikipedia.org/wiki/File:CellRespiration.svg

3. en.Wikipedia.org/wiki/File:Mi...%80%94Etc4.svg

4. Gropper SS, Smith JL, Groff JL. (2016) Advanced nutrition and human metabolism (7th ed.). Cengage.

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17.3.4: Anaerobic Respiration (keep but move to 9.2?)

Conditions without oxygen are referred to as **anaerobic**. In this case, the pyruvate will be converted to lactate in the cytoplasm of the cell as shown below.

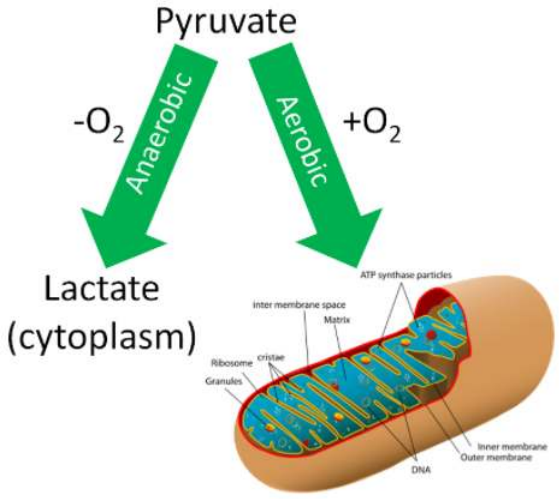


Figure 9.2.2.2.1 Pyruvate fork in the road, what happens depends on whether it is aerobic or anaerobic respiration[1]

What happens if oxygen isn't available to serve as the final electron acceptor? As shown in the following video, the ETC becomes backed up with electrons and can't accept them from NADH and $FADH_2$.

Web Link
Video: What happens when you run out of oxygen? (0:37)

This leads to a problem in glycolysis because NAD is needed to accept electrons, as shown below. Without the electron transport chain functioning, all NAD has been reduced to NADH and glycolysis cannot continue to produce ATP from glucose.

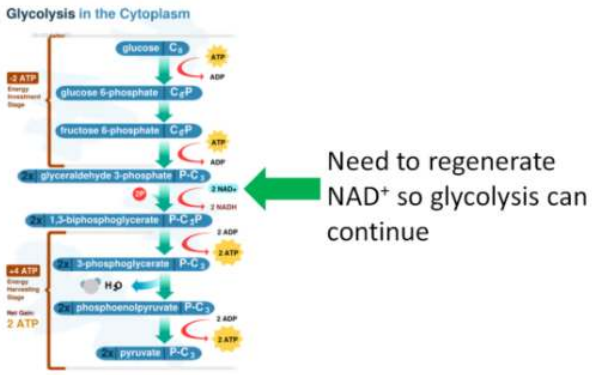


Figure 9.2.2.2.2 Why NAD needs to be regenerated under anaerobic conditions[2]

Thus, there is a workaround to regenerate NAD by converting pyruvate (pyruvic acid) to lactate (lactic acid) as shown below.

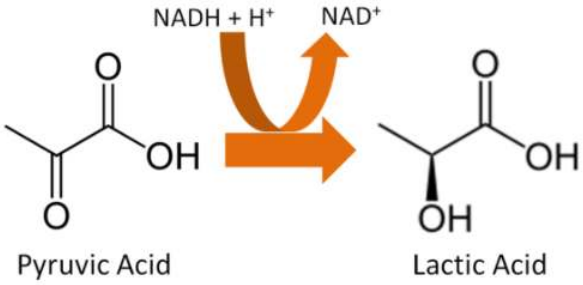


Figure 9.2.2.2.1 3. The conversion of pyruvic acid to lactic acid regenerates NAD[3,4]

However, anaerobic respiration only produces 2 ATP per molecule of glucose, compared to 32 ATP for aerobic respiration. The biggest producer of lactate is the muscle. Through what is known as the Cori cycle, lactate produced in the muscle can be sent to the liver. In the liver, through a process known as gluconeogenesis, glucose can be regenerated and sent back to the muscle to be used again for anaerobic respiration forming a cycle as shown below.

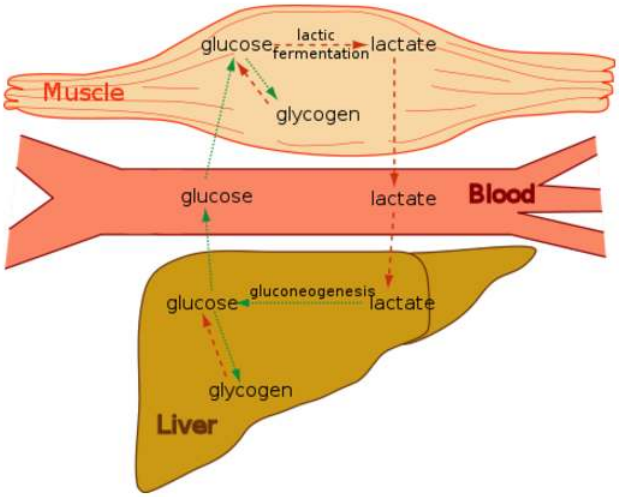


Figure 9.2.2.2.4 The Cori cycle[5]

It is worth noting that the Cori cycle also functions during times of limited glucose (like fasting) to spare glucose by not completely oxidizing it.

Contributors

Brian Lindshield and Claudia Kelley

References & Links

1. simple.Wikipedia.org/wiki/Mi..._en_(edit).svg
2. en.Wikipedia.org/wiki/File:CellRespiration.svg
3. en.Wikipedia.org/wiki/Pyruvi...D-skeletal.png
4. en.Wikipedia.org/wiki/Lactic...d-skeletal.svg
5. commons.wikimedia.org/wiki/F...iCycle-eng.svg

Video

What happens when your run out of oxygen? - http://www.youtube.com/watch?v=StXlo1W3Gvg

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17.4: Lipid Metabolism

Introduction

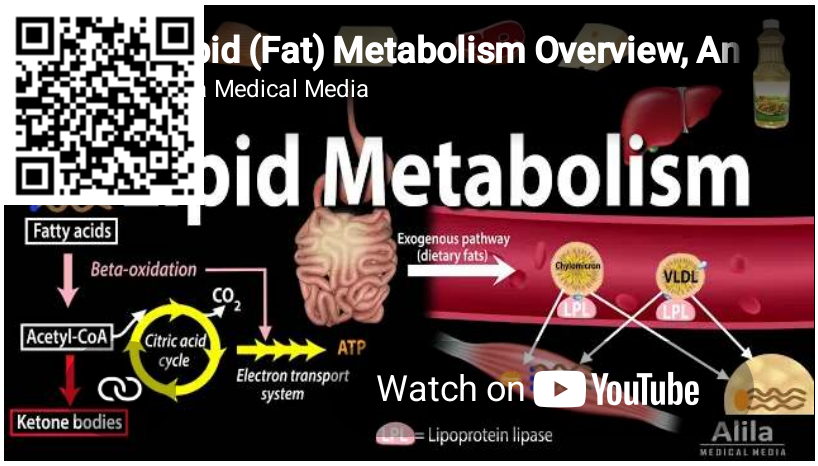
There are many metabolic pathways, processes, or reactions that are involved in the synthesis or degradation of lipids and compounds derived from them. Please note that excess intake of energy-containing nutrients, including the consumption of excess carbohydrates and excess protein as well as eating too much fat in one's diet can lead to 'fat production' or lipogenesis, whereby the human body is designed to almost have unlimited fat store capabilities.

Quick Overview of Lipid Pathways, Cycles, Processes, or Reactions - names & definitions

- **Lipolysis**
  - Triglyceride breakdown
  - Lipolysis is the cleavage of triglycerides to glycerol and fatty acids. There are two primary lipolysis enzymes: Lipoprotein lipase (LPL) and Hormone-sensitive lipase (HSL).
- **De novo Lipogenesis (Fatty Acid Synthesis)**
  - Thus, de novo lipogenesis is the synthesis of fatty acids, beginning with acetyl-CoA. Acetyl-CoA has to first move out of the mitochondria, where it is then converted to malonyl-CoA (3 carbons). Malonyl-CoA then is combined with another acetyl-CoA to form a 4 carbon fatty acid (1 carbon is given off as CO2). The addition of 2 carbons is repeated through a similar process 7 times to produce a 16 carbon fatty acid.
  - The newly generated triglycerides can be stored in fat cells, also known as adipocytes, and packaged within cytoplasmic lipid droplets.
- **Fatty Acid Oxidation (a.k.a beta-oxidation)**
- - To generate energy from fatty acids, they must be oxidized. This process occurs in the mitochondria, but long chain fatty acids cannot diffuse across the mitochondrial membrane (similar to absorption into the enterocyte). Carnitine, an amino acid-derived compound, helps shuttle long-chain fatty acids into the mitochondria.
- **Ketone Body Synthesis**
  - In cases where there is not enough glucose available for the brain (very low carbohydrate diets, starvation), the liver can use acetyl-CoA, primarily from fatty acids (but also certain amino acids), to synthesize ketone bodies (ketogenesis). The structures of the three ketone bodies; acetone, acetoacetic acid, and beta-hydroxybutyric acid.
- **Cholesterol Synthesis**
  - Acetyl-CoA is also used to synthesize cholesterol. There are a large number of reactions and enzymes involved in cholesterol synthesis.

Let's pull it all together what you learned about 'fat and lipid metabolism'

Please watch this short video to help you remember:



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17.4.1: Lipolysis (Triglyceride Breakdown)

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17.4.2: Fatty Acid Oxidation (Beta-oxidation)

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17.4.3: De novo Lipogenesis (Fatty Acid Synthesis)

De novo in Latin means "from the beginning." Thus, ***de novo* lipogenesis** is the synthesis of fatty acids, beginning with acetyl-CoA. Acetyl-CoA has to first move out of the mitochondria, where it is then converted to malonyl-CoA (3 carbons). Malonyl-CoA then is combined with another acetyl-CoA to form a 4 carbon fatty acid (1 carbon is given off as CO_2). The addition of 2 carbons is repeated through a similar process 7 times to produce a 16 carbon fatty acid[1].

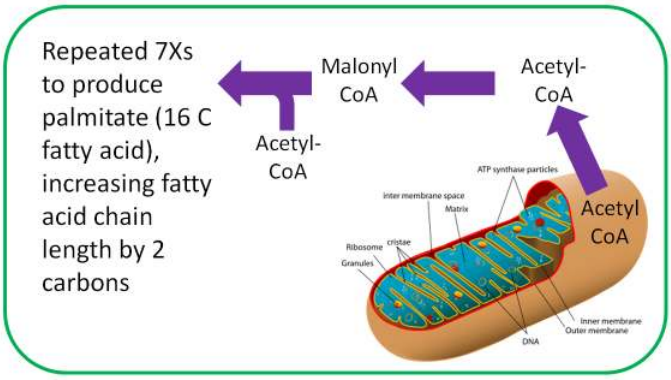


Figure 6.331 Fatty acid synthesis[2]

Most fatty acids synthesized will be esterified into triglycerides for storage.

References

1. Gropper SS, Smith JL, Groff JL. (2008) Advanced nutrition and human metabolism. Belmont, CA: Wadsworth Publishing.
2. en.Wikipedia.org/wiki/Mitochondrion

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17.4.4: Ketone Body Synthesis

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17.4.5: Cholesterol Synthesis

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17.4.6: Claudia's new lipid page - here Feast or Famine ?

Copied from "Blake, J. S., Munoz, K. D., & Volpe, S. (2019). *Nutrition: From Science to You* (4th ed.). Pearson." . . . I love the pictures and am wondering if Delmar's graphic champ might be able to reproduce?

How Does Metabolism Change during the Absorptive and Postabsorptive States?

Explain how metabolism changes during the absorptive, postabsorptive, and starvation stages of food intake.

Once food has been digested, the amino acids, monoglycerides, and triglycerides are absorbed and available to be used by the body. We refer to this as the **absorptive state**, or that period within 4 hours following a meal in which anabolic processes exceed catabolic processes. During the absorptive state, the body uses glucose as the primary source of energy (see the **Table Tips, Important Advice for Maintaining Energy Levels**). Later, when you need energy during sleep, between meals, or when you're too busy to eat, your body uses the glucose stored as glycogen, and the fatty acids and glycerol stored in triglycerides, for fuel. This is referred to as the **postabsorptive state**, or the period of time usually more than 4 hours after eating, such as during the late afternoon or overnight. Hormones regulate both the absorptive and postabsorptive states.

absorptive state

Period after you eat when the stomach and small intestine are full and anabolic reactions exceed catabolic reactions.

postabsorptive state

Period when you haven't eaten for more than 4 hours and the stomach and intestines are empty. Energy needs are met by the breakdown of stores.

TABLE TIPS

Important Advice for Maintaining Energy Levels

A table shows tips for maintaining energy levels.

8.4-9 Full Alternative Text

During the Absorptive State, Metabolism Favors Energy Storage

Metabolism adjusts to either provide energy for immediate use or store it for later, depending on your energy needs and intake. In the normal process of eating, if you consume more kilocalories than you require for your immediate energy needs, your metabolism favors anabolic reactions for the sake of storing the excess kilocalories for later use. For instance, if you eat excess protein, the excess is converted to fatty acids and stored as a triglyceride. If you overconsume carbohydrates, the anabolic reactions include converting the excess carbohydrates to glycogen. Once the glycogen stores are full, carbohydrates are converted to fatty acids.

Take a close look at **Focus Figure 8.15**, which illustrates the catabolic and anabolic pathways of the absorptive state.

FOCUS Figure 8.15 Metabolism during the Absorptive State

Metabolism during the absorptive state.

Figure 8.15 Full Alternative Text

Carbohydrates Are Stored as Glycogen

Although glucose is essential to red blood cells and *neural* (nervous system) cells, neither of these cell types can convert glucose to its storage form, glycogen, nor can they convert excess glucose to fat. Only liver and muscle cells can convert excess glucose to glycogen for storage.

Remember that dietary glucose arrives first at the liver from the portal vein. If glucose levels are high, the liver converts glucose to glycogen through glycogenesis or releases the glucose for circulation to other tissues. Enzymes in muscle cells can also convert excess glucose to glycogen. The body has a limited ability to store glycogen, however, and only about 1 percent of body weight is in the form of glycogen.

Liver glycogen plays an important role in maintaining glucose homeostasis. When intake of dietary carbohydrate is low, blood glucose levels drop. The glycogen stored in the liver can be broken down into glucose through glycogenolysis and released into the blood. However, about 12–18 hours after eating, liver glycogen levels are nearly depleted.

Even though muscle cells have a high storage capacity for glycogen, they lack the enzyme that can release glucose into the blood. In essence, glucose is “trapped” in the muscle to be used for energy or stored as glycogen; it is not used to maintain blood glucose levels.

Excess Carbohydrates and Amino Acids Are Stored as Triglycerides

Carbohydrates are first stored as glycogen. After those stores are full and energy needs are met, excess carbohydrates form triglycerides. Once glucose has been oxidized to acetyl CoA, it enters lipogenesis, forming fatty acids that are stored in the adipocytes. This conversion is very costly—almost 25 percent of the kilocalories glucose provides must be used to generate enough ATP to convert the glucose to fatty acids—and inefficient.

The same is true for excess amino acids. Protein is first used for the numerous functions it provides to the body before excess is converted to fatty acids. In this process, amino acids are first deaminated, then the remaining carbons are converted to acetyl CoA and formed into fatty acids. Both ketogenic and glucogenic amino acids can be catabolized and converted to fatty acids through pyruvate and acetyl CoA pathways, but the process is highly inefficient.

Fatty Acids Are Stored as Triglycerides

The body stores excess kilocalories in any form as triglycerides through the process known as lipogenesis, or fatty acid synthesis. Fatty acid synthesis begins with the two-carbon gateway molecule acetyl CoA. This molecule eventually becomes a long-chain fatty acid that attaches to a glycerol backbone and is stored as a triglyceride in fat cells.

The metabolic pathway to store dietary fat requires little energy (only about 5 percent of the stored energy within the fatty acid) and only a few steps; therefore dietary fat is easier to store as body fat than are dietary carbohydrate or protein. Lipogenesis is a separate anabolic pathway that synthesizes fatty acids to be stored and is not just a reversal of the reactions involved in the breakdown of fat. In fact, the two processes take place in different parts of the cell. Fatty acids are synthesized in the cytoplasm rather than in the mitochondria, where fats are oxidized. Lipogenesis also differs from fat oxidation in the way it’s affected by glucagon and insulin. Glucagon stimulates lipolysis, which provides the fatty acids for beta-oxidation. Insulin has the opposite effect: It inhibits the breakdown of fat and promotes fatty acid synthesis.

During the Postabsorptive State, Metabolism Favors Energy Production

Many Americans consume more than enough kilocalories to meet their energy demands, a fact which is reflected in the current obesity crisis. But what happens when the opposite is true? That is, you’re too busy to consume enough food or you choose not to eat? Some people choose not to eat for a period of time, often for spiritual or religious reasons. For example, Muslims fast during the month of Ramadan, there are seven fasting days in the Jewish religion, and some Christians may fast during Lent. Regardless of the reason, when you do not consume enough kilocalories to meet your energy needs, your body enters a postabsorptive state—usually more than 4 hours after eating. The stomach and small intestine are empty and the need for energy is met from stored energy. **Focus Figure 8.16** illustrates the metabolic pathways that are active during the postabsorptive state.

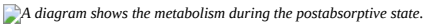

A diagram shows the metabolism during the postabsorptive state.

Figure 8.16 Full Alternative Text

Stores Are Depleted during Fasting

Whereas glycogen stores supply energy during short periods of fasting, such as overnight or between meals, the body adapts differently if you go more than 18 hours without consuming carbohydrates. Again, the body maintains blood glucose levels initially by tapping into liver glycogen through glycogenolysis. At the same time, an increase in lipolysis provides fatty acids for energy, thus reducing the use of glucose by the cell. Once liver glycogen has been depleted, gluconeogenesis is initiated, using amino acids, glycerol, pyruvate, and lactate to meet the body’s glucose needs.

Fat reserves are broken down faster as fasting continues. The brain must switch to an alternative source of energy—ketone bodies—derived from the fatty acids. A severe, prolonged fast, or starvation, depletes fat reserves and begins to break down muscle tissue to provide energy.

Ketogenesis Generates Energy during Prolonged Fasting

As you've learned in this chapter, acetyl CoA is generated from glucose (glycolysis) or fatty acid breakdown (lipolysis), both of which produce oxaloacetate that enters the TCA cycle. When deprived of carbohydrates, less oxaloacetate is available. The body depends less and less on glucose, and the TCA cycle slows. This allows acetyl CoA to accumulate because it is not metabolized in the TCA cycle. Some of the acetyl CoA produced by fatty acid oxidation in the liver is converted to ketone bodies, namely acetone, acetoacetate, and β-hydroxybutyrate.β-hydroxybutyrate.

Ketogenesis (the formation of ketone bodies, illustrated in **Figure 8.17**) occurs when there is an excess buildup of acetyl CoA. Ketogenesis reaches peak levels after an individual has fasted or consumed a limited-carbohydrate diet for 3 days. By the fourth day of a fast, the ketone bodies are providing almost half of the fuel used by the mitochondria.[2] The presence of ketone bodies is referred to as *ketosis* (described in **Chapter 4**). As you continue to fast, your brain switches from glucose to ketone bodies for fuel, thereby preserving blood glucose. Eventually, about 30 percent of the brain's energy comes from ketone bodies, with the rest provided by blood glucose.

ketogenesis

Formation of ketone bodies from excess acetyl CoA.

Figure 8.17 The Formation of Ketone Bodies

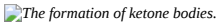

The formation of ketone bodies.

Figure 8.17 Full Alternative Text

Ketogenesis is a normal metabolic response to fasting, and ketosis is not life-threatening. The kidneys reabsorb ketone bodies to be used by other tissues for energy or excrete excess ketone bodies in the urine, thereby maintaining a balanced pH. Ketogenesis can be used therapeutically: A ketogenic diet is sometimes prescribed to control seizures in patients who have epilepsy and don't respond to medications. A ketogenic diet is difficult to follow and must be strictly monitored by a registered dietitian nutritionist. It is much stricter than the Atkins diet, another form of a ketogenic diet, requiring careful control of kilocalorie intake, fluids, and proteins.[3]

When very high concentrations of ketone bodies—which are acidic—accumulate in the blood, they lower the body's pH to dangerous levels. This condition, called **ketoacidosis**, most commonly occurs in individuals with untreated type 1 diabetes because, without insulin, glucose is not available to the cells. The body responds with hyperventilation, rapid and shallow breathing that increases excretion of CO2,CO2, which in turn increases the blood pH. If the level of ketone bodies continues to rise, diabetic ketoacidosis can lead to deep and labored breathing, impaired heart activity, coma, and even death.

ketoacidosis

Form of metabolic acidosis, or pH imbalance due to excess acid, that occurs when excess ketone bodies are present in the blood; most often seen in individuals with untreated type I diabetes.

THE TAKE-HOME MESSAGE

The differences in metabolism between the absorptive, or feeding, state and the postabsorptive, or fasting, state are listed in **Table 8.5**. During the absorptive state, anabolic reactions are favored. Carbohydrates are first used for ATP synthesis with excess stored as glycogen or triglycerides in the adipose tissue. Excess amino acids and dietary fat are also converted to triglycerides and stored. During the postabsorptive state, metabolism shifts to favor catabolic reactions. Fat is broken down to fatty acids to be used for ATP synthesis, while liver glycogen, glycerol, and glucogenic amino acids are used to maintain blood glucose levels. As fasting continues, glycogen stores are depleted, and muscle is broken down to provide amino acids for energy and gluconeogenesis. A lack of sufficient glucose in the blood can lead to excess breakdown of fat and the synthesis of ketone bodies, which can be used by the brain and muscles for energy, but are acidic. If ketogenesis is prolonged, ketoacidosis—an excessive level of ketones in the blood—can develop, leading to coma and even death.

Table 8.5 Metabolism during Feeding and Fasting

Metabolism during feeding and fasting.

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17.5: Protein Metabolism

Introduction

There are four protein metabolic pathways that will be covered in this section: Transamination -transfer of an amino group from one amino acid to another Deamination -removal of an amino group, normally from an amino acid. Gluconeogenesis -synthesis of glucose from a non-carbohydrate source. Protein Turnover/Degradation -liberation of amino acids from proteins.

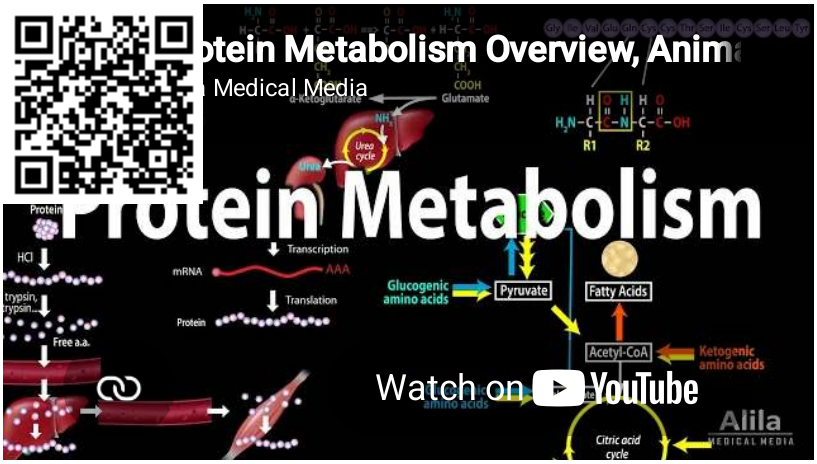
Quick Overview of Protein Pathways, Cycles, Processes, or Reactions - names & definitions

A previous section described how proteins are synthesized. Thus, this section will focus on how proteins and amino acids are broken down. There are four protein metabolic pathways to remember:

- **Deamination**
  - removal of an amino group, normally from an amino acid.
- **Transamination**
  - transfer of an amino group from one amino acid to another
- **Gluconeogenesis**
  - synthesis of glucose from a non-carbohydrate source.
- **Protein Turnover/Degradation**
  - liberation of amino acids from proteins.

Let's pull it all together what you learned about 'protein metabolism'

Please watch this short video to help you remember:



Contributors

Brian Lindshield and Claudia Kelley

Template:HideTOC

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17.5.1: Transamination, Deamination and Ammonia Removal as Urea

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17.5.2: Gluconeogenesis

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17.5.3: Protein Turnover/Degradation

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17.6: Alcohol Metabolism

Alcohol provides energy

Another energy source is alcohol - in fact, alcohol provides 7 kcal/g.[1] The alcohol we consume in form of beer, liquor or other spirits contains two carbon atoms and is known as ethanol.

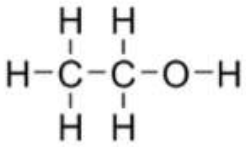


Figure 9.6.1 Structure of ethanol1http://en.Wikipedia.org/wiki..._structure.png

Ethanol is passively absorbed by simple diffusion into the enterocyte. Ethanol metabolism occurs primarily in the liver, but 10-30% is estimated to occur in the stomach[2]. For the average person, the liver can metabolize the amount of ethanol in one drink (1/2 ounce) per hour[3]. There are three ways that alcohol is metabolized in the body.

1. **Catalase** - an enzyme that we will cover again in the antioxidants section. Catalase is estimated to metabolize less than 2% of ethanol, so it is not shown below or discussed further[4].
2. **Alcohol dehydrogenase** (ADH) - This is the major ethanol-metabolizing enzyme that converts ethanol and NAD to acetaldehyde and NADH, respectively. Aldehyde dehydrogenase (ALDH) uses NAD, CoA, and acetaldehyde to create acetyl-CoA and to produce another NADH. The action of ADH is shown in the figure below.

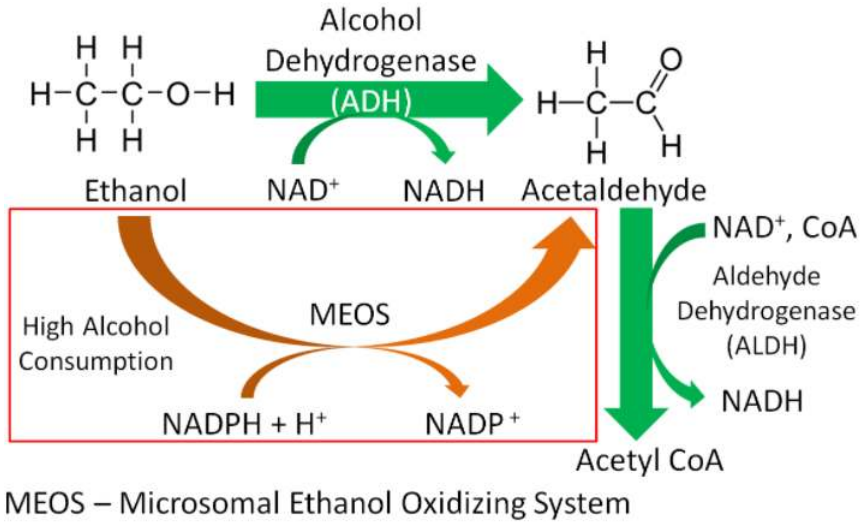


Figure 9.6.2 Ethanol Metabolism .Wikipedia.org/wiki/Acetal...de-2D-flat.svg

3. **Microsomal ethanol oxidizing system** (MEOS) - When a person consumes a large amount of alcohol the MEOS, is the overflow pathway, that also metabolizes ethanol to acetaldehyde. It is estimated that the MEOS metabolizes 20% of ethanol[3], and it differs from ADH in that it uses ATP to convert reduced nicotinamide adenine dinucleotide phosphate ($NADPH + H^+$) to $NADP^+$. The action of the MEOS is shown in the figure above.

At high intakes or with repeated exposure, there is increased synthesis of MEOS enzymes resulting in more efficient metabolism, also known as increased tolerance. ADH levels do not increase based on alcohol exposure. MEOS also metabolizes a variety of other compounds (drugs, fatty acids, steroids) and alcohol competes for the enzyme's action. This can cause the metabolism of drugs to slow and potentially reach harmful levels in the body[3].

Females have lower stomach ADH activity and body H_2O concentrations. As a result, a larger proportion of ethanol reaches circulation, thus, in general, females have a lower tolerance for alcohol. About 50% of Taiwanese, Han Chinese, and Japanese populations have polymorphisms in ALDH which cause the enzyme to have low activity[5]. This leads to buildup of acetaldehyde

and undesirable symptoms such as: flushing, dizziness, nausea, and headaches[2]. The following short video explains what happens when the MEOS system gets involved in alcohol metabolism.

Web Link

Video: MEOS Overflow Pathway

Contributors

Brian Lindshield and Claudia Kelley

References & Links

1. Blake, J. S., Munoz, K. D., & Volpe, S. (2019). *Nutrition: From Science to You* (4th ed.). Pearson.
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Video

MEOS Overflow Pathway - http://nutrition.jbpub.com/resources...?id=20&debug=0

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17.7: Excretion of Metabolic Waste Products

Not only does blood deliver nutrients and oxygen to cells, but equally important, blood also transports metabolic waste products away from cells. The thousands of metabolic reactions taking place in your cells generate more than just energy; metabolic waste products such as water, carbon dioxide, and nitrogen-containing compounds are produced as well.

Although the term elimination refers to the removal of solid waste (feces) from the body, the term excretion refers to the removal of metabolic waste products. The removal of solid and metabolic waste products are both vital to your health.

The main excretory organs involved in the removal of metabolic waste products include the liver, kidneys, lungs, and skin. Collectively, these organs help prevent the accumulation of toxic waste products by aiding in their removal. For example, the liver converts ammonia— a nitrogen-containing by-product of protein breakdown—into a less toxic substance called **urea**, which is released into the blood. The kidneys then filter the urea out of the blood so it can be excreted from the body in urine. This is why people with impaired kidney function often undergo a treatment called dialysis. Dialysis involves a special machine that performs similar functions of healthy kidneys. Without dialysis, toxic metabolic waste products would accumulate in the blood, eventually resulting in death.[1]

References

1. McGuire, M., & Beerman, K. A. (2017). *NUTR2*. (2nd ed.). Cengage Learning.

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17.8: Research Highlight - Metabolic Disorders

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... In the following publication... 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

APA citation

Further evaluation

To evaluate this publication further, it might help to...

References

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Glossary

Acceptable Macronutrient Distribution Range | [AMDR] The value of the energy-yielding nutrients carbohydrates, protein, and fat, expressed as percentages of total daily calorie intake, sufficient to provide total adequate energy needs; staying within the AMDR is associated with reducing the risks for developing chronic disease.

Acidic amino acids | Hydrophilic amino acids that are negatively charged.

added sugars | Sugars and other sweeteners (such as high-fructose corn syrup, honey, maple syrup, and molasses), that are added to food at the table, and are also ingredients in food products.

adequate | A dietary term signifying a diet that provides all nutrients, fiber, and energy in amounts sufficient to maintaining good health and body weight.

Adequate Intakes | [AI] If scientific data is insufficient to establish an EAR value, an AI is established based on the scientific data that is available. As with the RDA, the AI serves a nutrient-intake goal.

adipose tissue | Fatty tissue in the body that consists of masses of fat-storing cells.

adolescence | The period of the human life cycle between ages fourteen to eighteen, nutritionally speaking.

Age-related macular degeneration | [AMD] The progressive loss of central vision resulting from damage to the center of the retina, referred to as the macula.

albumin | A butterfly-shaped protein that plays a role in fluid balance, acid-base balance, and the transport of biological molecules.

Alcoholic Liver Disease | [ALD] Liver problems linked to excessive alcohol intake including fatty liver, alcoholic hepatitis, and cirrhosis.

alcohols | In chemistry, alcohols refer to a group of similar organic compounds, but in beverages the only alcohol consumed is ethanol.

amino acids | Simple monomers composed of the elements carbon, oxygen, hydrogen, and nitrogen.

amphiphilic | A compound that has both water-loving and fat-loving properties.

anabolism | All metabolic processes involved in building bigger molecules, which consume energy.

anaphylaxis | A life-threatening, extreme immune response to a food allergen. Anaphylaxis can result in difficulty breathing, swelling in the mouth and throat, decreased blood pressure, shock, and death.

Anorexia nervosa | A psychiatric illness in which a person obsesses over their weight and the food that they eat. Anorexia results in extreme nutrient inadequacy and, eventually, organ malfunction.

anorexia of aging | A condition that affects the elderly and is characterized by poor food intake.

antibodies | A protein that protects against unwanted intruders.

antioxidant | Any molecule that can block free radicals from stealing electrons.

arachidonic acid | An omega-6 essential fatty acid that is a precursor to the synthesis of eicosanoids.

atherosclerosis | Disease that is characterized by the deposition of plaques and fatty material in the walls of the body's artery, vein and blood vessel network.

atoms | The basic building blocks of all matter, living and nonliving.

balanced diet | A balanced diet supplies various types of foods in proportion to one another. With balance, foods rich in one nutrient leave room for foods that are rich in other nutrients.

basal metabolism | Metabolic pathways necessary to support and maintain the basic functions of the body (e.g. breathing, heartbeat, liver, and kidney function) while at rest.

Basic amino acids | Hydrophilic amino acids that are positively charged.

bile | A substance secreted by the liver that aids in the absorption and digestion of fats.

binge-eating disorder | A nonpsychiatric disorder characterized by periodic losses of control over eating. The periods of excessive overeating are not followed by fasting or purging. People who have this disorder are often overweight or obese.

biomarker | A measurable molecule or trait that is connected with a specific disease or health condition.

blood alcohol concentration | [BAC] A measurement of the level of alcohol in the blood stream, in terms of percentages; used to determine if an individual is legally intoxicated and driving while impaired.

Body mass index | [BMI] A measurement that associates height and weight, and is a more comprehensive measurement of body fatness than weight alone.

bone remodeling | Process in which bone tissue is broken down and then rebuilt at the same location.

bone resorption | Process in which osteoclasts secrete hydrogen ions, which acidify the local environment and dissolve the minerals in the bone tissue matrix.

Bulimia nervosa | A psychiatric illness characterized by frequent episodes of eating large amounts of food followed by purging.

caffeine | 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.

calcitonin | This hormone has the opposite effect of calcitriol and parathyroid hormone and aids in the maintenance of blood calcium levels by decreasing the calcium level as necessary.

calcium | The most abundant mineral in mineralized bone tissue. Good dietary sources of calcium are dairy products and many vegetables with low oxalate content, such as kale, collard greens, and okra.

calorie | A unit of energy; equivalent to the amount of energy required to heat 1 gram of water 1 degree Celsius.

Calorie control | Controlling energy intake so that energy requirements are being met but not exceeded.

carbohydrates | Organic molecules composed of carbon, hydrogen, and oxygen. There are two basic forms: simple sugars and complex sugars.

cardiorespiratory endurance | The cardiovascular system's ability to deliver oxygen and nutrients efficiently to fuel physical activity.

cardiovascular disease | A disease of the heart or blood vessels.

Celiac disease | An autoimmune disorder caused by an abnormal reaction of cells in the small intestine to a type of protein, called gluten.

cell theory | Cells are the most basic building units of life, all living things are composed of cells, and new cells are made from preexisting cells, which divide into two.

cellular respiration | The process by which the stored chemical energy in nutrients is transformed into cellular energy.

central nervous system | Neurons form the core of the central nervous system, which consists of the brain, spinal cord, and other nerve bundles. The main function of the central nervous system is to sense changes in the external environment and create a reaction to them.

chemical energy | Potential energy in chemical bonds.

chylomicron | Chylomicron clusters form when lipids are combined with carrier proteins in the cells of the intestinal lining. Chylomicron is a vehicle of transport for fats throughout the watery environment of the body to the liver and other tissues.

Chyme | A semiliquid mass of partially digested food that also contains gastric juices.

circulatory system | Comprised of the heart, blood, and blood vessels. Its main functions are to transport nutrients to all cells and transport wastes from all cells.

cis fatty acid | A fatty acid with the hydrogen atoms bonded to the same side of the carbon chain.

cofactors | Minerals that make up part of enzymes required for converting a substrate to an end-product.

collagen | A strong, fibrous protein made up of mostly glycine and proline amino acids.

commensal | an association between two organisms in which one benefits and the other derives neither benefit nor harm. [Oxford Languages]

complementary foods | A combination of foods that when consumed together (though not necessarily at the same time) contain all nine essential amino acids at adequate levels.

complete protein sources | Foods that contain all nine of the essential amino acids.

Concentration | The amount of particles in a set volume of water.

conditionally essential amino acids | Amino acids that become essential during certain times in life, such as child growth.

conditionally essential nutrients | Nutrients that are supplied only under special conditions or circumstances, such as pregnancy, stress, illness, or aging.

cortical bone | Dense, strong bone that surrounds trabecular bone tissue. Also called compact bone.

creatine phosphate | [PCr] Compound that provides a reserve of phosphate to regenerate ADP to ATP.

Dehydration | Water loss from the body without adequate replacement.

Dementia | A disorder of the nervous system characterized by changes in the normal activity of the brain.

Dementia | A disorder of the nervous system characterized by changes in the normal activity of the brain.

Denaturation | The physical changes that take place in a protein when it is exposed to abnormal conditions in the environment.

determinants of health approach | These are the conditions reflective of the circumstances in which people are born, live, work, and age. It assesses the conditions that shape circumstances such as money, power, and resources at the local, national and global levels.

determinants of health approach | These are the conditions reflective of the circumstances in which people are born, live, work, and age. It assesses the conditions that shape circumstances such as money, power, and resources at the local, national and global levels.

Dietary fibers | Polysaccharides that are highly branched and cross-linked and only found in plant-based foods, with the exception of chitin (which forms the exoskeletons of some animals).

Dietary fibers | Polysaccharides that are highly branched and cross-linked and only found in plant-based foods, with the exception of chitin (which forms the exoskeletons of some animals).

Dietary Reference Intakes (DRI) | A set of nutrient recommendations that includes the Estimated Average Requirements (EAR), Recommended Dietary Allowances (RDA), Adequate Intakes (AI), Tolerable Upper Intake Levels (UL) and Acceptable Macronutrient Distribution Range (AMDR).

diglycerides | A product of lipid digestion, consisting of a glycerol molecule that has two fatty acids attached.

Disaccharides | Two monosaccharides joined together.

Disease | Any abnormal condition that affects the health of an organism and is characterized by specific signs and symptoms.

Diverticulitis | A condition that occurs when the out-pocketings in the lining of the colon become inflamed. Symptoms include lower abdominal pain, nausea, and alternating between constipation and diarrhea.

docosahexaenoic acid (DHA) | An omega-3 fatty acid that is especially important for brain growth and development in infants.

dual energy X-ray absorptiometry (DEXA) | A procedure during which two X-ray beams pass through a person and calculate the amount of calcified tissue in grams per unit area of bone.

early childhood caries | A dental disorder characterized by decay within the primary teeth.

eating disorder | A behavioral condition that involves extreme attitudes and behaviors toward food and nutrition. These disorders are characterized by overeating or undereating, and include anorexia nervosa, binge-eating disorder, and bulimia nervosa.

eating disorder | A behavioral condition that involves extreme attitudes and behaviors toward food and nutrition. These disorders are characterized by overeating or undereating, and include anorexia nervosa, binge-eating disorder, and bulimia nervosa.

eicosanoids | Compounds derived from polyunsaturated fatty acids that control several body functions.

eicosapentaenoic acid (EPA) | An omega-3 fatty acid made from linolenic acid, found in fish.

embolism | Blood vessel obstruction caused by a mass, such as a detached blood clot or other foreign body, that circulates in the bloodstream.

emulsifiers | Compound that allow two immiscible liquids to combine so that no separation occurs.

Energy | The quantity of work a particular system can perform.

Energy | The quantity of work a particular system can perform.

energy balance | When energy intake is equal to energy expended.

energy drinks | Beverages containing extremely high levels of caffeine, which can augment the effects of the drug.

Energy metabolism | The metabolic pathways that release or store energy.

Enzymes | Proteins that conduct a specific chemical reaction in order to transform substrates into a product.

Epidemiological studies | Scientific investigations that define frequency, distribution, and patterns of health events in a population.

Epigenetics | A rapidly advancing scientific field, in which researchers study how non-gene factors affect gene expression.

Epigenetics | A rapidly advancing scientific field, in which researchers study how non-gene factors affect gene expression.

essential fatty acids | A fatty acid that the body cannot synthesize and must be supplied through the diet.

essential fatty acids | A fatty acid that the body cannot synthesize and must be supplied through the diet.

Estimated Average Requirements (EAR) | Average daily intake levels for nutrients estimated to meet the needs of 50 percent of the target group. Used in nutrition research and policy-making. EARs form the basis for which RDA values are set.

Estimated Energy Requirement (EER) | Energy intake values that have been established to preserve energy balance in healthy adults of a specific age, gender, weight, and height, and category of physical activity concurrent with good health.

Estrogen | Primary female reproductive hormone.

extrusion reflex | An involuntary reflex that causes infants to push food out of their mouths with their tongues.

failure-to-thrive (FTT) | A condition that is characterized by inadequate growth or weight gain due to any cause.

Fatty acids | An organic compound that contains a carboxylic acid (−COOH) group at one end and a methyl group at the other ($-CH_3$).

fermentable sugars | Sugars such as glucose, fructose, and maltose that are easily metabolized by bacteria in a process known as fermentation.

Flexibility | Capability of joints to move in a whole, wide range of motion.

Fluoride | A mineral that blocks tooth decay and is part of mineralized bone tissue. The primary dietary source is fluoridated water.

food additives | Natural or man-made substance added to a food product during the processing stage to improve its quality.

food allergy | After eating certain kinds of food, the immune system reacts shortly thereafter producing symptoms such as digestive troubles, swollen airways, hives, or possible death.

food allergy | After eating certain kinds of food, the immune system reacts shortly thereafter producing symptoms such as digestive troubles, swollen airways, hives, or possible death.

food desert | A location that does not provide access to affordable nutritious food.

food infections | Foodborne illness caused by bacteria, viruses, or parasites.

food infections | Foodborne illness caused by bacteria, viruses, or parasites.

food insecurity | The state of not having continual access to sufficient, safe, and nutritious food to achieve an active, healthy lifestyle.

food intoxications | Foodborne illness caused by natural toxins or harmful chemicals.

food intoxications | Foodborne illness caused by natural toxins or harmful chemicals.

food jag | A behavior exhibited by a young child who insists upon eating the same foods over and over again.

Food security | A state in which all persons in a community's population obtain a nutritionally adequate diet that is culturally acceptable throughout the year that is not dependent on emergency aid sources, but more so from local production.

Food security | A state in which all persons in a community's population obtain a nutritionally adequate diet that is culturally acceptable throughout the year that is not dependent on emergency aid sources, but more so from local production.

functional foods | Foods which do more than meet basic nutritional needs and could provide additional health benefits.

functional foods | Foods which do more than meet basic nutritional needs and could provide additional health benefits.

gastroesophageal reflux | A disorder that occurs when stomach acid rises into the esophagus. In infancy, it is characterized by coughing, choking, or vomiting after feeding.

Gastroesophageal reflux disease (GERD) | A persistant form of acid reflux, in which acidic contents of the stomach leak backward into the esophagus and cause irritation.

Genetically modified foods | Food products made from animals or plants that have undergone genetic engineering.

genome | Entire genetic information contained in an individual which is inherited from their parents.

gestational diabetes | A metabolic condition similar to Type 2 diabetes that occurs in some pregnant women.

Gestational hypertension | A possible complication of pregnancy characterized by raised blood pressure levels.

glycemic index (GI) | A measurement of the effects of carbohydrate-containing foods on blood-glucose levels.

glycogen | A highly branched macromolecule consisting of thousands of glucose monomers held together by chemical bonds.

glycogen | A highly branched macromolecule consisting of thousands of glucose monomers held together by chemical bonds.

Glycolysis | The first stage of glucose breakdown; a ten-step enzymatic process that splits glucose into two three-carbon molecules and yields two molecules of ATP.

HDLs | High-density lipoproteins are also known as "good cholesterol." It contains the maximum percentage of protein and a lower percentage of cholesterol and collects and transports excess cholesterol, returning it to the liver for reuse or excretion.

Healthy Eating Index (HEI) | A standardized tool based on a simple scoring system of dietary components used to assess whether the diets of Americans are improving and adhering to the dietary guidelines.

heat capacity | The capability of a substance to store heat.

hormones | Biological molecules transported in the blood that regulate cellular processes in other target tissues.

human life cycle | The span of a human life, which consists of different stages, including childhood, adolescence, adulthood, and old age.

Hyperlipidemia | A term that refers to any number of conditions characterized by excessive amounts of fat in the blood.

hypertension | Medical condition in which the force of blood against the arterial walls is high enough that it could lead to heart disease or other health problems.

IDLs | Intermediate-density lipoproteins transport a variety of fats and cholesterol in the bloodstream and are a little under half triacylglycerol in composition.

immune system | The immune system is made up of several different types of white blood cells and other components that act as barricades to foreign invaders. The functions of the immune system are to barricade, seek, recruit, attack, and destroy foreign invaders, such as bacteria and viruses.

immunoglobulins | Proteins produced by plasma cells that function as antibodies. In infancy, immunoglobulins pass from mother to infant via breast milk and provide passive immunity for the baby.

Interventional clinical trial studies | Scientific investigations in which a variable is changed between groups of people.

iron-deficiency anemia | A condition characterized by inadequate hemoglobin in the blood due to low iron levels.

Iron-deficiency anemia | A condition that develops from having insufficient iron levels in the body, resulting in fewer and smaller red blood cells containing lower amounts of hemoglobin. Signs and symptoms include fatigue, weakness, pale skin, shortness of breath, dizziness, swollen and sore tongue, and abnormal heart rate.

irradiation | The application of radiation for the purpose of sterilization and the removal of harmful pathogens.

Irritable bowel syndrome (IBS) | A disorder characterized by muscle spasms in the colon that result in abdominal pain, bloating, constipation, and/or diarrhea. There is no permanent structural damage to the large intestine.

keratin | A fibrous protein that provides skin, hair, and nails with structure.

kilocalorie (Calorie) | A kilocalorie is the amount of heat generated by a particular macronutrient that raises the temperature of 1 kilogram of water 1 degree Celsius (this is what is denoted on the Nutrition Facts panel).

Kinetic energy | Energy associated with motion.

Kwashiorkor | A syndrome of severe protein and micronutrient deficiency, characterized by swelling (edema) of the feet and abdomen, poor skin health, growth retardation, low muscle mass, and liver malfunction.

Lactation | The medical term for the process of producing and secreting breast milk.

lactose intolerance | A condition in which there is incomplete digestion of lactose. It is caused by a deficiency in the enzyme, lactase. Symptoms include diarrhea, bloating, and abdominal cramps.

LDLs | Low-density lipoproteins are also known as "bad cholesterol." It contains higher concentrations of triacylglycerols and lower concentrations of protein and is responsible for delivering cholesterol to the body's tissues.

life cycle | The stages of life one passes through until death.

lifestyle | Components of lifestyle are dietary habits, physical activity level, recreational drug use, and sleeping patterns, all of which play a role in health and impact nutrition.

linoleic acid | An omega-6 fatty acid that is essential for human health.

lipase | An enzyme responsible for the breakdown of triacylglycerols and phospholipids.

Lipids | A family of organic compounds composed of carbon, hydrogen, and oxygen. They are insoluble in water. The three main types of lipids are triglycerides, phospholipids, and sterols.

macronutrients | Nutrients that are needed in large amounts. Includes carbohydrates, lipids, proteins, and water.

macronutrients | Nutrients that are needed in large amounts. Includes carbohydrates, lipids, proteins, and water.

magnesium | A mineral that is part of mineralized bone tissue. The dietary sources are meat, fish, dairy products, whole grains, nuts, chocolate, and coffee.

magnesium | A mineral that is part of mineralized bone tissue. The dietary sources are meat, fish, dairy products, whole grains, nuts, chocolate, and coffee.

marasmic kwashiorkor | The combined syndrome of severe protein and energy deficiency, characterized by variable edema, emaciation, poor skin health, and growth retardation.

marasmic kwashiorkor | The combined syndrome of severe protein and energy deficiency, characterized by variable edema, emaciation, poor skin health, and growth retardation.

marasmus | A syndrome of severe protein and energy deficiency, characterized by emaciation, poor skin health, and growth retardation.

marasmus | A syndrome of severe protein and energy deficiency, characterized by emaciation, poor skin health, and growth retardation.

Mechanical breakdown | Includes mastication (chewing) and the muscular contractions of the stomach and small intestine that mash, mix, slosh, and propel food down the alimentary canal.

Mechanical breakdown | Includes mastication (chewing) and the muscular contractions of the stomach and small intestine that mash, mix, slosh, and propel food down the alimentary canal.

metabolic fitness | Ability to provide energy to the muscles during physical activity.

Metabolic homeostasis | The nutrients consumed and absorbed matches the energy required to carry out life's biological processes.

Metabolic syndrome | A medical condition in which people have three or more risk factors for Type 2 diabetes and cardiovascular disease.

Metabolism | The sum of all biochemical reactions that occur within a living cell to maintain life.

metastasis | Spread of cancerous cells from an original location to one or more new sites within the body.

metastasis | Spread of cancerous cells from an original location to one or more new sites within the body.

Micronutrients | Nutrients needed in smaller amounts. Includes vitamins and minerals.

Moderation | Not eating to the extremes, neither too much nor too little.

monoglycerides | A product of lipid digestion, consisting of a glycerol molecule with one fatty acid attached.

monosaccharide | The simplest unit of a carbohydrate.

muscle endurance | Quality of a muscle, or a group of muscles, to perform repetitive movements for a lengthy period of time.

muscular system | The muscular system allows voluntary movement as well as involuntary movements of other organ systems. It consists of skeletal muscle, the heart muscle, and smooth muscles.

mycotoxins | Natural, poisonous substance produced by certain molds and mushrooms that can cause foodborne illness.

myosin | A contractile protein in muscle cells.

Newborn jaundice | A condition that can occur within a few days of birth and is characterized by yellowed skin or yellowing in the whites of the eyes.

nitrogen balance | When the amount of protein input into the body equals the amount used up and excreted.

Nonpolar amino acids | Hydrophobic amino acids with side groups that are long or bulky.

Nutrient-dense foods | Foods that contain many nutrients per calorie.

nutrients | Substances required by the body that must be obtained from the diet.

Nutrition Facts panel | Found on most packaged foods, it contains specific amounts of nutrients and also compares the amounts of nutrients in the food and the recommended intake values. These comparisons are reported as percent DV.

Nutritional science | The investigation of how an organism is nourished, and how nourishment affects personal health, population health, and planetary health.

nutritionists | Health-care professional who works in the field of nutrition, but does not have registered credentials.

Obese | Having excess body fat (BMI greater than 30).

obesity | A metabolic disorder that leads to the overaccumulation of fat tissue, compromising overall health.

oligosaccharides | A carbohydrate that is a chain of a few (between three and ten) monosaccharides.

Organ systems | Two or more organs that support a specific physiological function.

organelles | A structural or functional unit in a cell that is constructed from several macromolecules bonded together.

organism | The complete living system capable of conducting all basic life processes.

Organs | A group of tissues arranged in a specific manner to support a common function.

osmolality | The total number of dissolved particles in a solvent, such as water.

osmosis | The movement of water through a selectively permeable membrane from an area where it is highly concentrated to an area where it is not as concentrated.

osmotic pressure | The force exerted by solutes at different concentrations on either side of a selectively permeable membrane.

Osteocytes | Star-shaped cells that are the most abundant cell type in bone tissue.

Osteoid | Bone tissue that is not mineralized.

osteomalacia | Similar to nutritional rickets, in adults this disease involves softening and weakening of the bones due to a lack of vitamin D or a problem metabolizing the vitamin.

osteopenia | Lower than normal bone mass.

Oxidation | The interaction between oxygen molecules and all the different substances they may contact. Can be more precisely defined as the loss of at least one electron when two or more substances interact and these substances may or may not include oxygen.

Oxidative stress | An imbalance in any cell, tissue, or organ between the amount of free radicals and the capablilities of its detoxifying and repair systems.

pancreatic amylase | Enzyme secreted by the pancreas that breaks down carbohydrates in the small intestine by breaking the glycosidic bonds between monomers.

peak bone mass | The greatest amount of bone mass that a person reaches during their lifetime.

peer review | evaluation of scientific, academic, or professional work by others working in the same field. [Oxford Languages]

pepsin | An enzyme secreted by stomach cells. It breaks the peptide bonds between amino acids, producing much shorter protein fragments.

peptide bond | The chemical bond that connects amino acids in a sequence.

percentage of Daily Value (percent DV) | The percentage of the amount of the nutrient in relationship to the DV. They are applicable only for a 2,000-calorie daily diet (not 2,500 calories).

peristalsis | Waves of smooth muscle contraction that propel food down the digestive tract.

Phospholipids | The second most common of the three basic lipids. Similar to triacylglycerols, phospholipids have an acid containing phosphorus in place of one of the fatty acids. These lipids appear in all cell membranes.

Phosphorus | A mineral that makes up a substantial part of mineralized bone tissue. The dietary sources are meat, fish, and dairy products, as well as processed foods, and cola beverages.

phytochemicals | Nonessential plant compounds considered to have a beneficial impact on human health.

pincer grasp | A grip that involves picking up an object with the fingers.

Platelets | Fragments of cells that, when stimulated by blood vessel injury, rush to plug up the wound.

point of unsaturation | The place on a molecule where additional hydrogen atoms can attach.

Polar amino acids | Hydrophilic amino acids that are not charged.

polysaccharides | A long chain of monosaccharides that may be branched or not branched.

polyunsaturated fatty acid | A fatty acid that contains two or more points of unsaturation.

prediabetes | A metabolic condition in which people have moderately high glucose levels, but do not meet the criteria for diagnosis as a diabetic.

preeclampsia | A possible complication of pregnancy marked by elevated blood pressure and high levels of protein in the urine.

preventive nutrition | The use of dietary practices to reduce disease and promote health and well-being.

primary prevention | Actions taken to avoid developing a disease before it starts.

protein folding | A sequence of amino acids transforms into its dictated shape.

protein turnover | The processes of continually breaking down proteins and building new ones.

Proteins | Macromolecules composed of chains of organic monomeric subunits, called amino acids. Amino acids are simple monomers composed of carbon, oxygen, hydrogen, and nitrogen.

Randomized clinical interventional trial studies | Scientific investigations which incorporate a change in the variable being tested between groups of people and are therefore capable of determining a causal relationship.

reactive oxygen species | Molecules containing oxygen that have unpaired electrons and are highly reactive.

Recommended Dietary Allowances (RDA) | Based upon the EAR, these are nutrient-intake goals designed to meet the requirements of 97 to 98 percent of the target group for a given nutrient.

risk factor | A variable that is linked to an increased probability of developing a disease or adverse outcome.

sarcopenia | The age-related decline in muscle mass.

satiety | The sensation of feeling full; determined by mechanical and chemical signals relayed from the periphery.

scientific method | The process of inquiry that involves making an observation, coming up with a hypothesis, conducting a test of that hypothesis, evaluating results, gathering more supporting evidence, and coming up with a conclusion.

secondary prevention | Strategies focused on halting or reversing a disease after it has developed.

Sedentary behavior | Activity during which energy expenditure is no more than one and one-half times the amount of energy expended while at rest (examples include sitting, reclining, or lying down while awake).

smoking point | The temperature at which fat gives off a pungent blue gas.

Socioeconomic status | A measurement dependent on three variables; income, occupation, and education.

SoFAS | An acronym for solid fats and added sugars.

SoFAS | An acronym for solid fats and added sugars.

Soluble fiber | Fiber that attracts water and turns to gel, which slows digestion. Soluble fiber is readily fermented in the colon by bacteria into gases and waste byproducts.

Solutes | Any dissolved substances in a fluid.

subsidies | Federal funding given to an agricultural producer to provide assistance and support.

Sugar alcohols | Carbohydrates that occur naturally in some fruits and vegetables; however they are industrially synthesized by yeast and other microbes for use as food additives.

supplements | Vitamins, minerals, and herbs which are taken in addition to your regular diet to promote healthy body functions or to target specific body parts.

sustainable food system | A system that can meet the needs of the current generation while providing food for generations to come without negatively impacting the environment.

T-score | Compares the patient's BMD to the averaged BMD of a healthy thirty-year-old population of the same sex.

taste threshold | Minimum concentration at which taste sensitivity to a food or substance can be perceived.

Thirst | An osmoregulatory mechanism to increase water input.

Tissues | A group of cells that share a common structure and function and that work together.

Tolerable Upper Intake Levels (UL) | The highest average daily nutrient-intake level at which a nutrient can be consumed before it poses a risk of toxicity.

trans fatty acid | A fatty acid that has hydrogens attached on opposite sides of the carbon chain.

Triacylglycerols | The most common of the three basic classes of lipids and the main form fat takes in both diet and the human body. A triacylglycerol is made up of three molecules of fatty acids and one molecule of glycerol.

Type 1 diabetes | A metabolic disease in which cells in the pancreas are killed by an abnormal response of the immune system, causing a lack of insulin in the body.

Type 2 diabetes | A metabolic disease of insulin insufficiency; also caused by muscle, liver, and fat cells no longer responding to the insulin in the body.

Type 2 diabetes | Occurs when the pancreas produces enough insulin initially, but the body is unable to use the hormone properly (insulin resistance).

Variety | Consuming an abundance of foods from different food groups on a regular basis.

visceral fat | Fat deposited in the abdominal cavity.

Vitamin D | Both a vitamin and a hormone, vitamin D plays an essential role in maintaining calcium homeostasis. A deficiency in vitamin D compromises bone health.

Vitamin K | A vitamin that acts as a coenzyme that modifies proteins important for bone health. The dietary sources are green vegetables such as broccoli, cabbage, kale, parsley, spinach, and lettuce.

VLDLs | Very low-density lipoproteins formed in the liver from the remains of the chylomicron.

waist-to-hip ratio | Waist circumference divided by hip circumference.

wellness | Achieving balance and integration of aspects that affect quality of life, including physical, mental, emotional, social, environmental, and spiritual dimensions.

Glossary

Sample Word 1 | Sample Definition 1

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