Principles of NUTRITION



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NUTR 150: Principles of Nutrition

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Chapter 1: Introduction to Nutrition Science

1.1

Nutrition Science

1.1 Nutrition Science

The importance of physical nourishment in the form of food and water was made clear to our first parents when they were introduced into the Garden of Eden.

> *Genesis 2:16 And the LORD God commanded the man, saying, of every tree of the garden thou mayest freely eat…*[1]

A significant amount of work was then required to maintain a food supply when Adam and Eve were cast out of the Garden of Eden.

> *Genesis 3: 17-19 …cursed is the ground for thy sake; in sorrow shalt thou eat of it all the days of thy life; Thorns also and thistles shall it bring forth to thee; and thou shalt eat the herb of the field; In the sweat of thy face shalt thou eat bread, till thou return unto the ground; for out of it wast thou taken: for dust thou art, and unto dust shalt thou return.*[1]

Those scriptural glimpses frame the longstanding human concern with food; today, modern science builds on those truths to explain what food is made of and how it sustains life.[2]

Since the time of Adam and Eve, food has been a vital part of human life. While the need for nourishment has remained constant, our understanding of how food affects health and well-being has grown significantly over time. We have been blessed with additional light and understanding regarding the chemical composition of food, how the human body digests and absorbs food, and how the components of food then maintain the body processes necessary for life. What we call **nutrition** today, is the sum of all these processes. The discipline of **nutrition science** is the investigation of how an organism is nourished, and how nourishment effects personal health, population health, and planetary health. Nutrition science includes a broad spectrum of disciplines such as biology, physiology, immunology, biochemistry, food science, agriculture, education, psychology, and sustainability.

Spiritual Insight

"Modern prophets have consistently taught that the Word of Wisdom is both a spiritual law and a practical guide that blesses physical health and spiritual sensitivity, reminding us that divine commandments often operate in harmony with natural law (Doctrine and Covenants 89)."[3] The promised blessings of the word of wisdom are connected to obedience to covenant living. Caring for our bodies is both a physical and a spiritual act that invites thoughtful stewardship over our daily choices (our body is a temple - 1 Corinthians 6:19-10)[1]

Nutrition Science History

Historical records show that early scientists recognized links between food and health. As far back as 1500 B.C., Egyptian writings suggested a connection between night blindness and eating liver. In 300 B.C., texts from the school of Hippocrates recommended eating raw beef liver soaked in honey to treat this condition. During the Middle Ages, a Dutch physician wrote:

Who does not at night see right

Eats the liver of a goat

He will then see better at night[4]

Through observation and experimentation, these early healers identified a food based treatment for night blindness. Centuries later, scientists discovered that liver is rich in vitamin A, the nutrient responsible for preventing and treating night blindness.[4]

The process of nutrition discovery continued into more recent history. Scurvy, a disease that devastated millions of sailors during long sea voyages through the mid-1800s, was eventually traced to a lack of vitamin C. Symptoms of scurvy included weakness, fatigue, bleeding gums, swollen legs, joint pain, bruised skin, poor wound healing, and even death.



Bruising and skin hemorrhaging from scurvy by Wellcome Library, London is licensed under CC BY 4.0

In the 1700s, James Lind conducted dietary experiments with sailors in the British Royal Navy to explore whether scurvy was linked to a nutrient deficiency. His research showed that scurvy could be prevented by eating citrus fruits. Although Lind is often credited with this discovery, historical records suggest that other health practitioners had observed the connection between citrus and scurvy for centuries before his work.[5]

In the 1930s, scientists identified the specific compound in citrus fruits that cures scurvy. They named it ascorbic acid, meaning "without scurvy acid," also known as vitamin C.

Many essential nutrients have similar stories of discovery that highlight the ongoing progress of nutrition science.[6] "The gradual discovery of nutrients through observation and experimentation reflects a pattern consistent with

gospel teaching: truth is revealed 'line upon line' (2 Nephi 28:30)[7], whether in spiritual understanding or scientific knowledge."

Importance of Nutrition

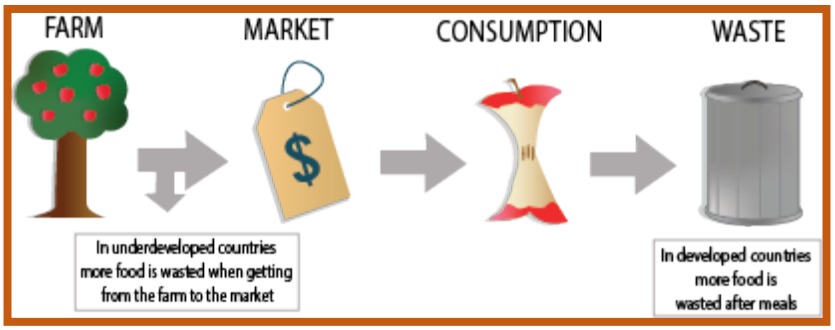
Without adequate nutrition, the human body may not grow or perform optimally. Nutritional inadequacy can lead to disease and sometimes even death. However, the opposite is also true. Eating food in excess can be just as detrimental. In the old testament in Daniel 1, Daniel, Shadrach, Meshach, and Abednego declined the king's rich food and wine in favor of a simpler diet consistent with their beliefs; as a result, they were described as physically healthy and spiritually faithful (Daniel 1:8–17)[1], illustrating the connection between wise dietary choices and overall well-being.

Today, increased access to food, supplements, and medical treatment has reduced the number of people suffering from nutrient deficiencies. Nonetheless, in 2023 nearly 733 million people, about one in eleven worldwide, were undernourished.[8] Many of these individuals are children. Inadequate intake of calories, protein, and micronutrients such as iron, vitamin A, and zinc remains common in many parts of the world. The term "**food insecurity**" describes the lack of consistent access to sufficient amounts of safe and nutritious foods. Major causes of global food insecurity include armed conflict, internal violence, civil unrest, and political crises that displace people from their homes. Weather extremes such as droughts, floods, and hurricanes, along with changing climate patterns and disease outbreaks, can further disrupt food production and distribution.



In many areas of the world, limited transportation and refrigeration make it hard to get foods to local markets unspoiled and keep them fresh while being sold. Created by AP

Economic challenges such as high unemployment rates or inflation can further limit access to food. In many places, poor infrastructure and limited access to technology make food insecurity worse. Long distances between farms and markets, especially on rough or undeveloped roads, can prevent food from reaching buyers before it spoils. It is estimated that one third of all food produced globally is lost or wasted.[9]



Food waste in underdeveloped and developing countries verses developed countries. Created by AP

Even when enough food is available, many people still suffer from hidden hunger. **Hidden hunger** refers to inadequate intake or absorption of essential vitamins and minerals. It is common among those who are undernourished, but it can also occur when calorie needs are met without enough variety in the diet. For example, someone may eat enough rice and beans to meet energy needs, but without fruits and vegetables, vitamin and mineral deficiencies will still develop.

In developed countries, hidden hunger often results from diets high in calories but low in nutritional quality. Whether or not physical signs of deficiency are visible, your dietary intake directly affects your quality of life. The ability to think clearly, communicate, hope, dream, serve, attend school, or go to work is all influenced by the quality of the food you eat.

Key Takeaways

- Nutrition supports physical, mental, and spiritual health.
- Nutrition science has a long history of discovery.
- Undernutrition and hidden hunger remain global issues.
- Food insecurity has many causes worldwide.
- Overnutrition and poor diet quality are growing concerns.
- Your diet directly impacts your daily life and abilities.

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1.2

Types of Malnutrition

1.2 Types of Malnutrition

Prep Videos

What is malnutrition?



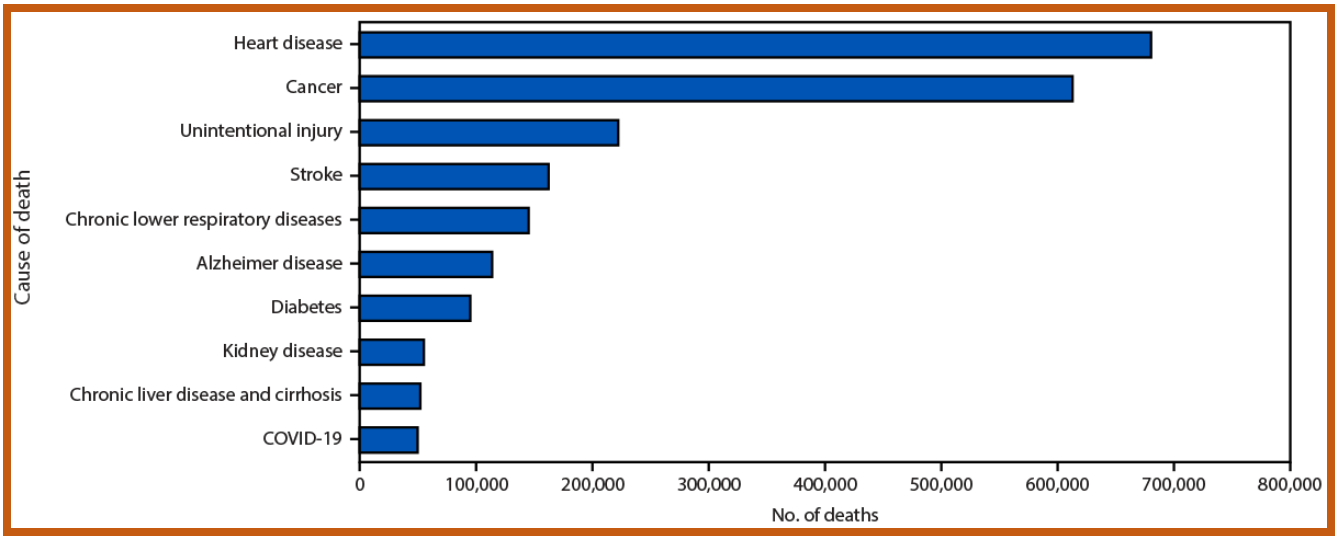
Watch on YouTube

The prefix “mal” means bad and when coupled with nutrition would imply “bad-nutrition.” Therefore, malnutrition can refer to both overnutrition or undernutrition.

Overnutrition occurs when there is an overconsumption of nutrients from food or supplementation to the point at which health is adversely affected. This could manifest as excessive caloric consumption leading to obesity or consuming vitamins or minerals at toxic levels.

Undernutrition occurs when there is insufficient consumption of Calories, vitamins, or minerals. This can manifest as impaired growth and development or specific vitamin and mineral deficiency diseases such as scurvy (vitamin C deficiency). It is important to understand that initially there may not always be clear signs of malnutrition. The potential serious effects will often develop over time.

Overnutrition and Chronic Disease



Cause of Death in the United States: Report provided by the Center for Disease Control [1]

Overnutrition may manifest itself in several different forms. Excessive vitamin or mineral intake from supplementation or fortified foods may lead to toxicities. Despite vitamin and mineral toxicity (overconsumption), the magnitude of the public health concern from this kind of excess is much less concerning than the over consumption of calorie rich, nutrient poor food that is becoming common throughout the world.

This type of “malnutrition” is a contributor to chronic diseases such as heart disease, type 2 diabetes, hypertension, and some cancers. Many of the health problems of modern society could be minimized by simply addressing poor diet choices. Cancer and heart disease account for over 40% of the total deaths in the US[1]. Both diseases have a strong relationship to dietary habits. Globally, high income countries like the United States display a similar pattern. The rate of chronic disease like heart disease and stroke are increasing in underdeveloped countries, but the highest percentage of deaths in underdeveloped countries are related to infectious disease such as respiratory and

diarrheal disease and neonatal deaths. This can be contributed to factors such as higher rates of undernutrition, lack of access to healthcare and limited sanitation services.

High income countries, 2021	Low income countries, 2021
Heart Disease	Lower Respiratory Infections
COVID-19	Stroke
Stroke	Heart Disease
Alzheimer's disease and other dementias	Malaria
Trachea, bronchus, lung cancers	Preterm birth complications
Chronic obstructive pulmonary disease	COVID-19
Colon and rectum cancers	Diarrhoeal Diseases
Lower Respiratory Infections	Tuberculosis
Kidney Diseases	Birth asphyxia and birth trauma
Hypertensive heart disease	HIV/AIDS

Leading causes of death globally in high-income and low-income countries (listed in order from highest to lowest) [2]

Undernutrition and Deficiency Disease

Severe undernutrition is rare in developed countries, but it is a leading cause of death of children in underdeveloped countries. Nutrition status of children can be determined by following growth measures such as height and weight. Severe undernutrition can contribute to stunting (low height for age) and/or wasting (low weight for height). Recent global estimates indicate that approximately 148 million children under five years of age are stunted and about 45 million are wasted worldwide.[3]

The impact of nutrition on a child's health is profound and long-lasting. Good nutrition supports healthy brain development, helping children reach their full potential in school, work, and life. It improves their overall quality of life and can even contribute to the economic growth of their community and country. In contrast, poor nutrition can lead to serious health problems, lower productivity, higher health care costs, and a continued cycle of poverty and poor health. [3,4]

Inadequate intake of Calories and certain vitamins and minerals can also negatively affect the immune system; consequently, undernourished children commonly die from bacterial or viral infections (diarrheal diseases, respiratory infections, tuberculosis etc…). In 2024, the World Health Organization reported that nearly half the deaths among children under 5 years of age are linked to malnutrition. The majority of these deaths occurred in low- and middle-income countries.[5]

Vitamin A, iron, and iodine are some of the most common vitamin and mineral deficiencies in the world. It is estimated that 190 million children under the age of 5 are affected by vitamin A deficiency alone.[6] Lack of vitamin A impairs immunity which increases death rates from infectious disease, primarily in low income countries. It also results in night blindness and a severe deficiency of vitamin A can result in permanent blindness. Global efforts to increase vitamin A intake has led to extensive supplementation programs, fortification of foods, promoting food sources rich in vitamin A such as orange fleshed sweet potatoes, and genetic modification to increase vitamin A levels in foods. Deficiencies of iron, iodine and other vitamins and minerals can be equally as damaging. Increased access to food preservation techniques like drying and canning, has improved access to nutrient-rich foods. Despite these efforts, deficiency of some nutrients remains high in some areas of the world.



An infant being screened for undernutrition by Jonathan Torgovnik/Getty Images/Getty Images Europe

A good example of how knowing about food and using some creativity can make a big difference comes from early American history during the time of the Mormon pioneers. In the winter of 1846, as many as 600 immigrants died at Winter Quarters, mostly from scurvy (a serious illness caused by not getting enough vitamin C). While serving as a missionary in England, George Albert Smith learned that potatoes, when eaten with the skin, could help prevent scurvy. Because potatoes could be stored and used during the winter, he encouraged the pioneers to eat them to stay healthy. George Albert Smith became known as the "Potato Saint" for his efforts.[7] This historical account illustrates how applied nutritional knowledge, even when incomplete by modern standards, can significantly improve community health outcomes when paired with leadership, compassion, education, inspiration and a desire to serve.

Moderately low intake of vitamins and minerals may not cause obvious physical signs of a deficiency, like night blindness, but can still affect a person's quality of life. Health professionals often call this a **sub-clinical deficiency**, meaning there are no clear outward symptoms yet. For example, someone with a slightly low vitamin A intake may have a higher risk of infections even though they do not show other obvious signs of deficiency. Even when outward signs are absent, inadequate nutrition can quietly limit human potential—physically, cognitively, and socially—underscoring the importance of both scientific understanding and compassionate community response

Double Burden of Malnutrition

Although undernutrition continues to be an issue worldwide, a noticeable number of underdeveloped countries are progressing economically, socially, and culturally. As a country becomes more urban or developed, access to education increases which leads to improved employment opportunities. As a result, income increases, but the time available to prepare traditional foods decreases.[8] Urbanization within developing countries yields a greater availability of food in the country. Access to a variety of foods results in a more Westernized diet which includes higher fat, added sugars, meat, milk and overall calories than typically consumed in the traditional diet.[9] The loss of the traditional lifestyle results in an increased consumption of ultra-processed foods. **Ultra-processed foods** are foods that contain many added ingredients (such as fat and sugar) and have gone through multiple refinement processes.

Examples include foods such as soda, some fast foods, candy and packaged foods like chips and cookies.

The shift to a westernized diet composition in developing countries is leading to the development of overnutrition in previously largely undernourished countries. Thus, countries that were mainly concerned about undernutrition and infectious disease are now also faced with the burden of chronic diseases caused by this transition to an industrial lifestyle, adoption of a Western diet high in ultra-processed foods and decreased physical activity.[10,11]

The increased availability of cheap, ultra-processed foods in developing countries is a central factor to the global growing presence of the double burden of malnutrition. A focus on eating a variety of locally availably healthy foods is critical to curb the declining global health trend and to minimize the presence of the double burden of malnutrition.



School lunch in Ghana, Africa showing a mixture of traditional and westernize food options. Donated by Amanda Christensen

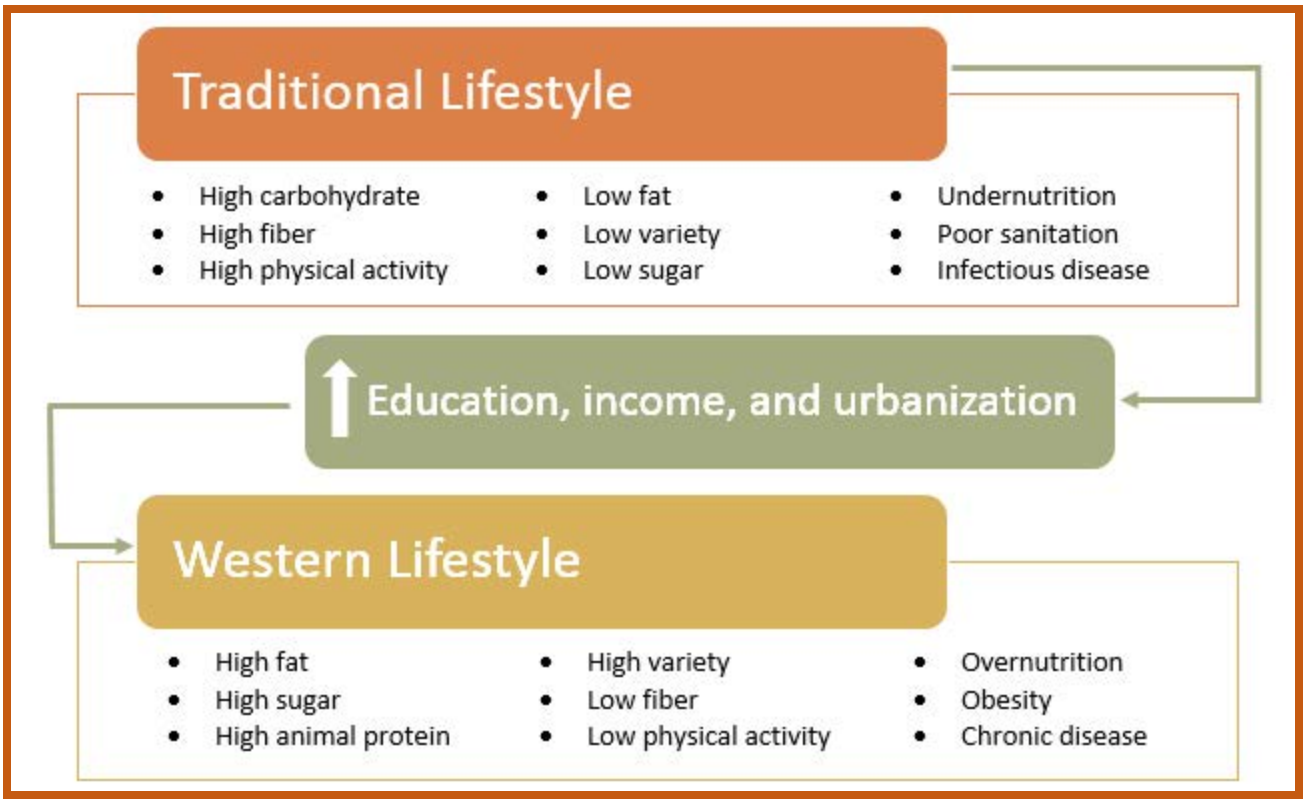


Figure 1.3: The nutrition transition from a traditional lifestyle to a Western lifestyle

Key Takeaways

- Malnutrition includes both undernutrition and overnutrition.
- Overnutrition contributes to chronic diseases like heart disease and type 2 diabetes.
- Undernutrition is still a major cause of illness and death, especially in children.
- Micronutrient deficiencies (like vitamin A and iron) remain common worldwide.
- The "double burden of malnutrition" refers to undernutrition and overnutrition occurring together in populations of even individuals.

- A focus on diverse, local, nutrient-rich foods is essential to improve global health.

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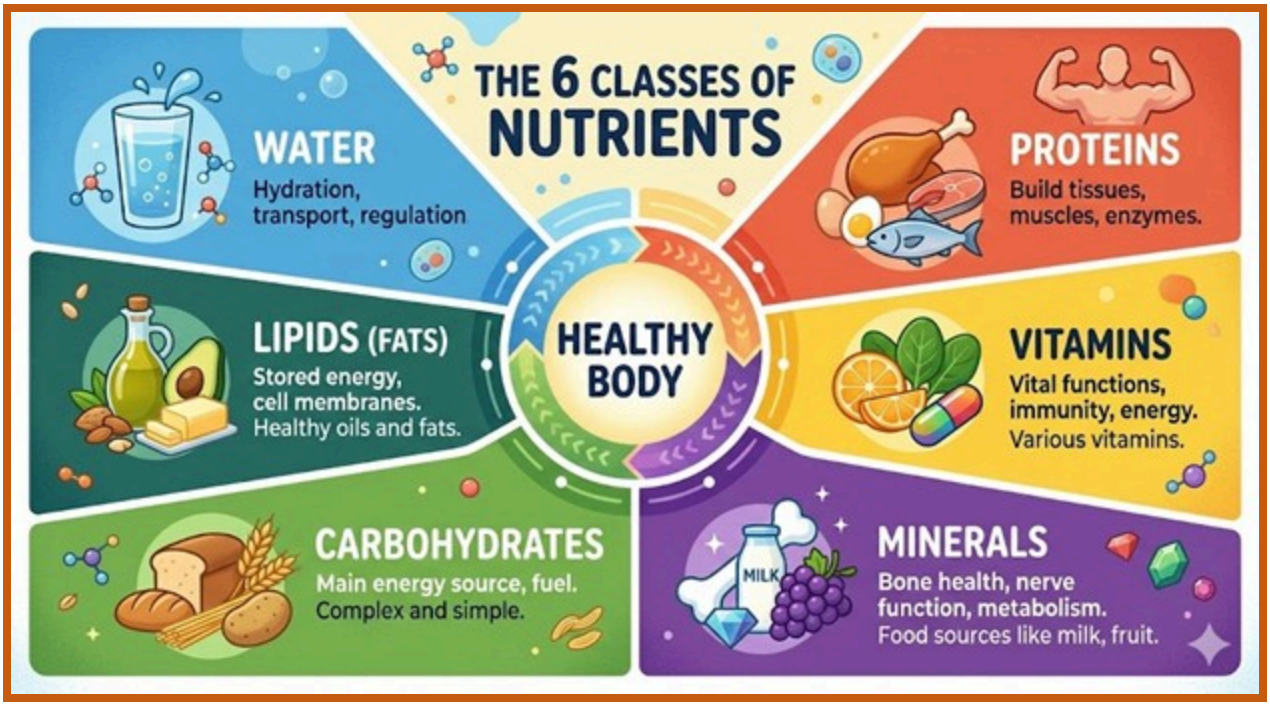
1.3

Food Components and Energy

1.3 Food Components and Energy

Nutrients

A nutrient is a substance in food that is required by the body and provides either energy (calories), structure to the body, and/or regulates body processes. There are six classes of nutrients required for the body in order to maintain overall health and proper function. They are carbohydrates, lipids, proteins, water, vitamins, and minerals.



The six classes of nutrients required for normal bodily functions such as Water, Proteins, Vitamins, Carbohydrates, Lipids (Fats), and Minerals (AI generated)

Essential Nutrients

The foods we eat contain many nutrients. Not all nutrients found in food are considered **essential**. An essential nutrient cannot be made by the body or made in sufficient quantities and must be consumed in the diet to prevent deficiency. For example, cholesterol is an important structural and regulatory component of cell membranes. Our body needs cholesterol to operate properly, but because our liver can manufacture cholesterol from other food substances it is not an essential nutrient. In contrast humans cannot make vitamin C, so for humans and some other mammals it is an essential nutrient.



Most mammalian species do not require vitamin C to sustain life. They can make vitamin C from the sugar glucose. Humans along with higher primates, guinea pigs, and fruit bats lack the genetic material necessary to manufacture vitamin C.

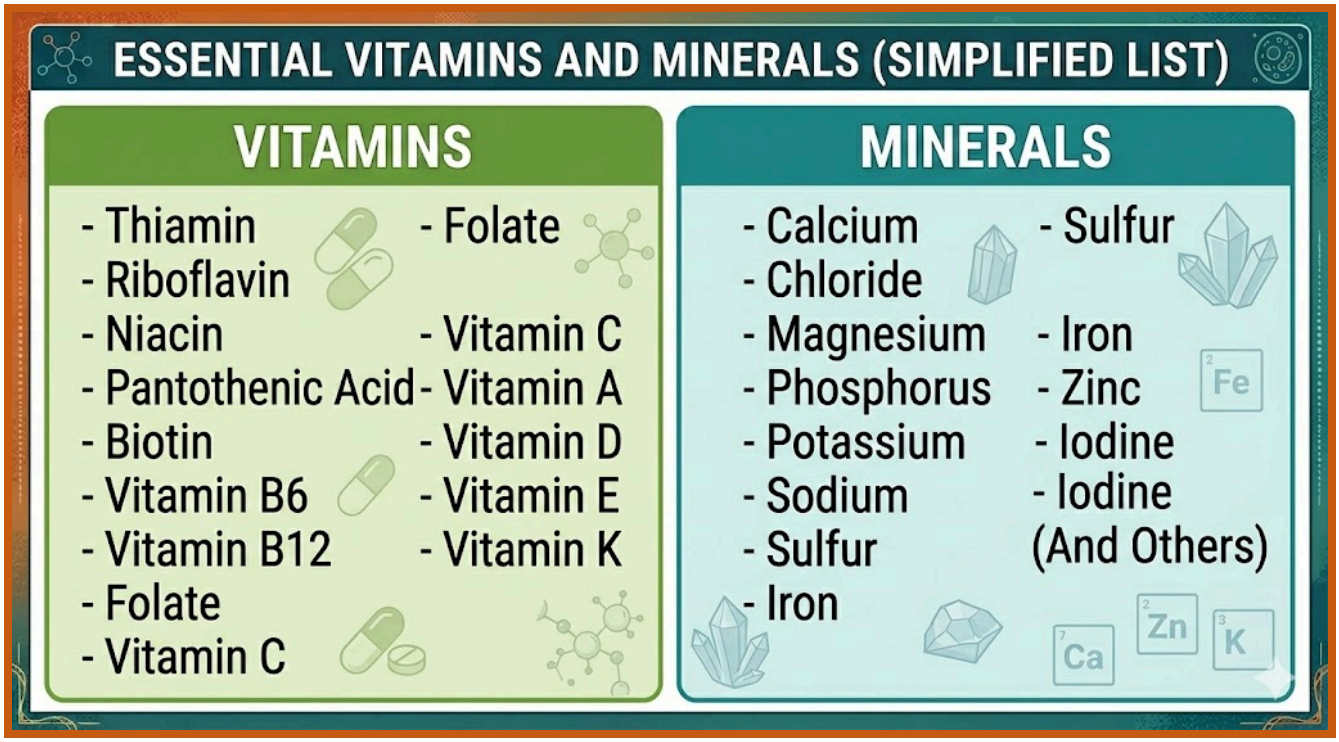
Macronutrients

One way we classify nutrients is by the amount needed in the diet. Nutrients that are needed in large amounts are called **macronutrients**; this category includes water, carbohydrates, proteins and lipids. The amounts needed by the body are typically measured in grams. Carbohydrates, proteins, and lipids are involved in regulatory, structural, and energy functions. For instance, carbohydrates' primary function is to provide energy to the body. The central nervous system and red blood cells are particularly dependent on carbohydrates for fuel. Another function of carbohydrate is at the cellular level. Cells use carbohydrates to communicate messages inside the cell or between cells. In this role, carbohydrates serve as a regulator.

Lipids have significant roles in all three areas. They are an excellent energy source, but also provide the primary structure for every cellular membrane in the body. A number of the hormones that regulate body processes are created from lipids, such as vitamin D, estrogen, and testosterone. Protein can also be used for energy, but its primary role in the body is structural and regulatory. Most enzymes and some hormones (like insulin) are protein based, and both are regulators of body processes. Water does not provide energy, but inadequate amounts will be fatal before any other nutrient. Its importance lies in its ability to help regulate body temperature, remove waste products, and provide the medium in which most of the body processes occur.

Micronutrients

Micronutrients are nutrients required by the body in lesser amounts but are still essential for carrying out bodily functions. Micronutrients include the vitamins and minerals. The micronutrients specialize in regulating body processes. For example, the vitamins and minerals do not provide any energy, but they help the body extract energy from carbohydrates, proteins, and fats. Several of the minerals also have a significant role in providing structure; bones are a good example because of their high content of calcium and phosphorus. Just about all body processes that are essential for life require one or more of the vitamins and minerals to be present.



Micronutrient Categories

Micronutrients are typically measured in milligrams and micrograms. To put macronutrients and micronutrients in perspective, let's compare a person's requirements for iron (a micronutrient) and carbohydrate (a macronutrient). A 20-year-old female would typically consume about 250 *grams* of carbohydrate per day. Her iron requirement is 18 *milligrams* per day. Although there is a difference between 250 and 18, it is vital to consider the units of measurement to appreciate the magnitude of the difference. A clearer perspective can be given by comparing these nutrients using the same measurement unit.

Carbohydrate (macronutrient) needed per day: 250,000 milligrams

Iron (micronutrient) needed per day: 18 milligrams

We can take that one more step. Some micronutrients are needed in even smaller quantities than iron. For instance, a 20-year-old female would only need about 15 micrograms of vitamin D a day. A milligram is 1000 micrograms. So, if we put her need for carbohydrates, iron and vitamin D in the same units they would look like this:

Carbohydrate needed per day: 250,000,000 micrograms

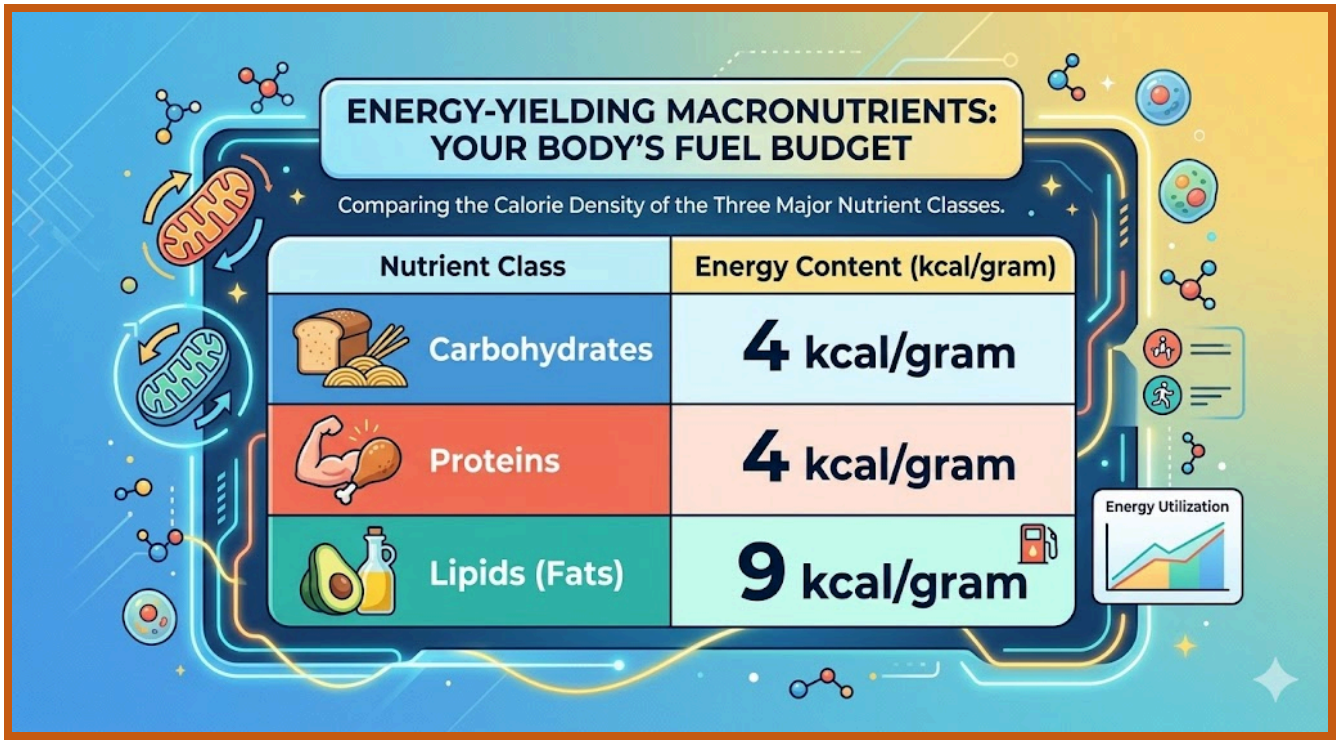
Iron needed per day: 18,000 micrograms

Vitamin D needed per day: 15 micrograms

This comparison shows that a 20-year-old female would need 16,666,666 times more carbohydrate per day than she needs vitamin D.

Nutrients That Contain Energy

The energy containing nutrients include carbohydrates, lipids and proteins. These can be metabolically processed into cellular energy. The energy from these macronutrients comes from their chemical bonds. When the bonds are broken, the energy released can be transformed into ATP (Adenosine Triphosphate). ATP is the compound used to fuel body functions. A unit of measurement for food energy is the calorie, by definition (1 calorie) is the amount of energy that is needed to raise the temperature of 1 gram of water 1 degree centigrade. Food calories are typically listed in kilocalories (also written as kcals or Calories with a capital "C") amounts. For instance, a fun size snickers bar has about 74 kcals or Calories. But in other disciplines such as physics food may be listed as calories (with a small c). In this case a fun size snicker bar would be listed as containing 74,000 calories. (1 Kcal = 1 Calorie = 1000 calories)



Calorie content of the energy-containing nutrients (AI generated)

Estimating Energy

By knowing the Calories contained in a gram of carbohydrate, protein, lipid and alcohol, total calories in a food product can be determined if the amount of energy yielding nutrients in the product is known.

For example, if a person knows that a peanut butter and jelly sandwich has:



Peanut Butter and Jelly Sandwich (AI generated)

65 grams of carbohydrate

14 grams of protein

32 grams of lipid

…then the total Calories of that sandwich can be determined when the macronutrient content is known.

Energy yielding Nutrient	Total Grams	Calories/Gram	Total Calories
Carbohydrates	60	4	240 (60x4)
Protein	14	4	56 (14x4)
Lipid	32	9	288 (32x9)
		Total	584

Determination of Calories when given grams of carbohydrate, protein, and fat countries created by AP

While these numbers are useful for estimating Calories from grams of carbohydrate, protein and fat it is important to recognize they are only a rough estimate of the actual Calories/gram. The actual amount of Calories/gram varies depending on other factors such as the specific type of carbohydrate, protein or fat used in a product as well as their interaction with other food components.

Estimating Percent of Calories

Recommendations for energy yielding nutrients are often given in ranges of percent of total calories. These percentages show what proportion of total calories is recommended for each macro nutrient. The percent of calories from fat, protein and carbohydrates can be compared to the Acceptable Macronutrient Distribution Ranges (AMDR) listed below.

Energy Yielding Nutrient	Acceptable Macronutrient Distribution Range
Fat	20-35%
Carbohydrate	45-65%
Protein	10-35%

AMDR recommendations for adults 19 years and older

To calculate your percent of calories from fat, protein, or carbohydrate you divide the number of calories provided from each nutrient by the total calories and then multiply by 100. Below is an example of how to calculate percent of calories from carbohydrate.

Jills Diet

252 grams of carbohydrates (1008 kcal)

84 grams of proteins (336 kcal)

52 grams of fat (468 kcal)

Total kcal = 1812 kcal

How to determine percentage of calories from carbohydrate

Take the total calories from carbohydrate = 1008 kcal

Divide it by the total kcal = 1812

Convert it to a percentage by multiplying by 100

1008 kcal/1812 kcal X 100= 56%

Key Takeaways

- *The six essential nutrients are carbohydrates, lipids, protein, water, vitamins, and minerals.*
- *Essential nutrients must be eaten because the body can't make enough on its own.*
- *Macronutrients are needed in gram amounts; micronutrients are needed in much smaller milligram or microgram amounts.*
- *Carbohydrates, fats, and proteins provide energy; water, vitamins, and minerals do not.*
- *AMDR (recommended nutrient ranges) suggests 45—65% of calories from carbohydrates, 10—35% from protein, and 20—35% from fat.*

References (see below)

U.S. Department of Agriculture & U.S. Department of Health and Human Services. (2026). *Dietary Guidelines for Americans, 2025–2030* (10th ed.)

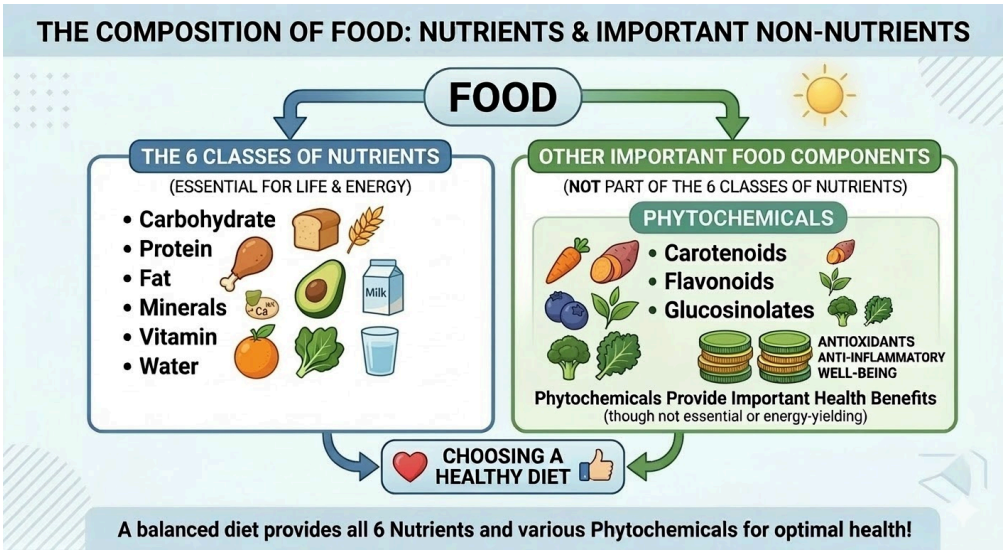
1.4

Phytochemicals and Nutrient Density

1.4 Phytochemicals and Nutrient Density

Phytochemicals

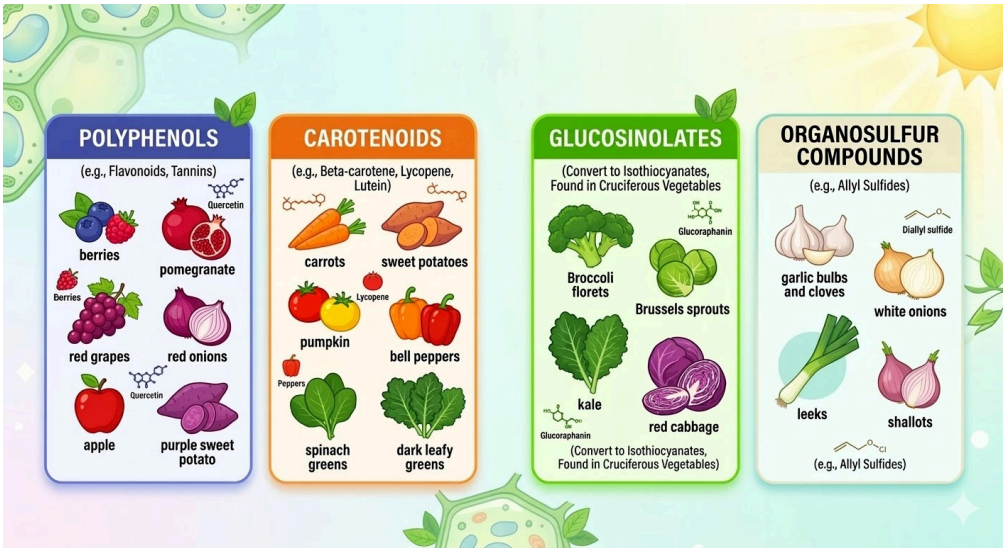
If all essential nutrients (carbohydrates, proteins, fats, vitamins, minerals, and water) were removed from a plate of food, what would be left? Surprisingly, many substances would remain. These compounds are not classified as essential nutrients but may still offer health benefits. Most are found in plant-based foods like fruits, vegetables, whole grains, nuts, and seeds. They are known as **phytochemicals**, a term that comes from the Greek word *phyto*, meaning "plant."



Where phytochemicals fit in food

Phytochemicals are not considered essential nutrients because there is no known deficiency disease caused by not consuming them. However, they may offer many health benefits when included in the diet. Observational studies consistently show that higher fruit and vegetable intake is associated with a lower risk of cardiovascular disease, some cancers, and cognitive decline.[1,2] It is believed that phytochemicals may play a role in these protective effects. Thousands of

phytochemicals have been identified, and many more will likely be discovered. Their presence in whole foods is one reason why eating a varied, plant-rich diet is recommended and why relying on supplements instead of healthy food choices is discouraged. Research suggests that the health benefits of fruits and vegetables result from the combined action of many nutrients and phytochemicals working together rather than from single isolated compounds.[3] Because of this complexity, relying on dietary supplements instead of whole foods is generally discouraged. Some common phytochemical types and their food sources are highlighted in the image below.



Some common phytochemicals found in whole foods that promote good health. Created by AI

Phytochemicals represents a complex and evolving area of study. Only a few phytochemical groups are highlighted above, but each group contains multiple layers of subgroups. For example, flavonoids belong to the larger polyphenol group, which also includes phenolic acids, stilbenes, and lignans. Within the flavonoid group are subcategories like flavanols, flavones, flavanols, isoflavones, and proanthocyanin's. Each subgroup contains specific compounds. For instance, quercetin, kaempferol, and myricetin are found in the flavanol subcategory. These compounds are found in particular foods, often in high concentrations.[3,4] This is an exciting area of research, and scientists are only beginning to understand the complex roles these substances may play in human health. Foods rich in phytochemicals—such as fruits, vegetables, nuts, seeds, and whole grains—are common examples of the 'wholesome herbs' and fruits described in the Word of Wisdom.[4] While modern nutrition science uses terms like phytochemicals to describe beneficial plant compounds, the principle of consuming plant foods has long been emphasized in scripture (See Alma 46:40.)[5]

Nutrient Density

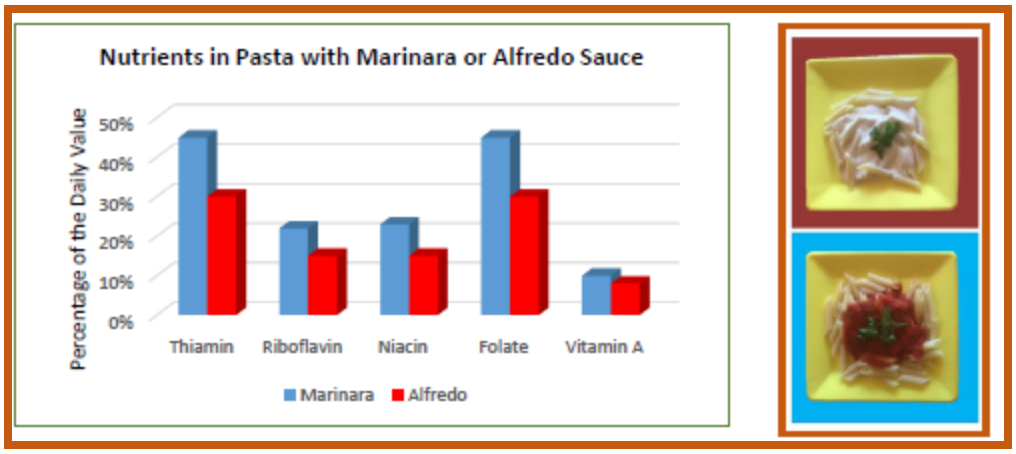
One of the most important concepts in building a healthy diet is the principle of **nutrient density**. Nutrient density refers to the amount of essential nutrients such as vitamins, minerals, protein and fiber, relative to the number of calories in food. Each day, we have two main nutritional goals: Consuming enough calories to fuel our activities and obtaining sufficient essential nutrients, especially vitamins and minerals, to support normal body function.

In many developed countries, the challenge is meeting vitamin and mineral needs without exceeding calorie requirements. Foods that provide high amounts of vitamins and minerals for relatively few calories are considered nutrient dense. For example, compare a serving of a baked potato and French fries. Although both are made from potatoes, the baked potato provides significantly more vitamins and minerals. The figure below illustrates this principle.

Description of nutrient density comparing the same calorie serving of French fries and a baked potato

When 75 Calories of butter (about three fourths of a tablespoon) are added to the baked potato, the nutrient density decreases. While the baked potato with butter is still more nutrient dense than French fries, the gap narrows. This is because purified fats like butter add Calories without contributing many vitamins or minerals, which lowers the overall nutrient density of the food.

The same principle applies to many everyday food choices. Choosing a different spread, sauce, or milk product can help increase the nutrients you get per Calorie. The image below shows how the nutrient density of pasta can change based on the sauce that is added. The red and blue bars indicate the amount of nutrients per calorie in the pasta with marinara verses pasta with alfredo. The higher blue bars indicate a higher nutrient density in the pasta with marinara.



The amount of the selected nutrients provided in a 320 Calorie serving of a pasta with alfredo or marinara in relation to the Daily Value.

By focusing on nutrient density each day, a person can better meet their nutritional needs while staying within a calorie range that supports a healthy weight.

Key Takeaways

- *Phytochemicals are plant-based compounds that are not essential nutrients but may promote health.*
- *A diet rich in fruits, vegetables, nuts, seeds, and whole grains provides many beneficial phytochemicals.*
- *Phytochemicals likely work with other food components in ways supplements cannot replicate.*
- *Nutrient density refers to the amount of nutrients in a food relative to its calorie content.*
- *Nutrient-dense foods help meet vitamin and mineral needs without excess calories.*
- *Choosing whole, unprocessed foods and thoughtful additions (like sauces or spreads) can improve nutrient density.*

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1.5

Promoting Change

1.5 Promoting Change

Choices, Accountability and Change

Nutrition experts would hope that when food choices are made, a consideration of the short- and long-term health impact would be included in the process. While that certainly plays a role, it is well recognized that it is not likely the primary stimulus behind food choices. When a group of college students were surveyed regarding how they make food choices, the top reasons they gave were principles such as time, availability, cost, taste or preference.[1]



Eating empty calories is a choice Photo by Russell Ferrer on Unsplash

Preferences of parents, family traditions, cultural influences, and religious affiliations have likely influenced the types of food eaten as a child. Research suggests that early food experiences can influence dietary patterns later in life.[2] We may have learned certain foods are associated with happy times and others were used to soothe stress. While none of these are inherently bad reasons to choose certain foods, when these influences are left unbalanced and unsupported by an understanding of healthy nutrition principles, they can establish patterns that may lead to significant long-term health problems. The challenge is how to identify food habits that may be detrimental, and then, how to change them.



Insect-eating is common throughout the world. In many areas, it represents a food choice based on culture, availability, cost, and nutrition.

Stages of Change

People make many food-related decisions each day, often automatically or out of habit.[3] Some choices we make based on learned habits. Others we may make based on the situation and how we feel. A trip to the grocery store is filled with decisions to make. Aisle after aisle thousands of foods and products call out for attention. Advertisements, health claims, colorful packaging all influence our choices.

From a gospel perspective, life is designed for us to make choices and learn from our choices. So how do you promote healthy eating in a way where one can act and not be acted upon? It is important to realize behavior change does not usually happen all at once. Instead, there are distinct phases that a person goes through while making a change. Each of these phases of change has different strategies that can help a person move to the next phase. The Stages of Change model also know as the Transtheoretical Model can be used to develop the appropriate strategies to help guide behavior change. Behavior change models such as the Stages of Change help explain how people often move through phases when adopting new habits. While these models come from behavioral science, the principle that individuals have the power to choose and act is consistent with restored gospel teachings on agency.[4]



Stages of change and change strategies

The first stage in the Stages of Change model is **Precontemplation**.[5] This stage is where the person is either not aware of the needed change or is not interested in changing. In other words, they are comfortable where they are.

Trying to tell a person how to change their diet when they are not aware of the need or not interested in the change is an example of "acting upon" the person and is often met with resistance. Instead, an appropriate strategy would be to increase the individual's awareness that the change would be beneficial for them. This action can help move the person to the next stage.

In the **Contemplation** stage, the person weighs the possible benefits versus the barriers to making the change.[5] For instance, a person would consider the pros of eating healthier to reduce the risk for chronic diseases against the cons of having to change preferences for food before making a decision. Strategies that may help the person move to the next stage include helping the person identify the perceived barriers and misconceptions and discussing their concerns.

The next stage is **Preparation**, which involves making a plan to change within the next 30 days.[5] For instance, at this stage a person would plan to include more physical activity into their life by walking 30 minutes a day or plan to buy more fruits and vegetables and put them on the counter where they can be seen. A useful strategy to help a person at this stage is to suggest realistic goals and give practical suggestions.

The next stage is **Action**, which involves the person following their plans.[5] Beneficial strategies for this stage are to provide encouragement, support, and positive reinforcement. After six months of action, the person moves to the **Maintenance** stage

where those actions may become part of one's lifestyle and habits.[4] Change doesn't happen all at once – it is a process that requires constant effort and dedication.

Behavior change models such as the Stages of Change help explain how people often move through phases when adopting new habits. While these models come from behavioral science, the principle that individuals have the power to choose and act is consistent with restored gospel teachings on agency. Agency is an eternal principle. As the Lord states in the scriptures, "For the power is in them, wherein they are agents unto themselves."[5]

Key Takeaways

- *Most food choices are influenced by taste, cost, time, and habits, not just health.*
- *Early food experiences, culture, and emotions shape long-term eating patterns.*
- *The Stages of Change model explains how people move from awareness to lasting behavior change.*
- *Each stage (Precontemplation, Contemplation, Preparation, Action, and Maintenance) requires different support strategies.*
- *Long-term change takes time, consistency, and encouragement.*
- *Change and agency are central to both health and spiritual growth.*

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2

Chapter 2: Evaluating Nutrition Information

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2.1. The Science of Nutrition

2.2. Evaluating Strength of the Evidence from Scientific Studies

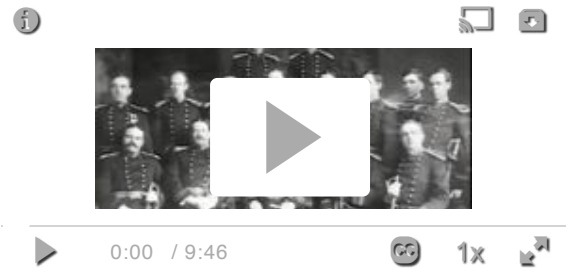
2.3. Tools for Evaluation

2.1

The Science of Nutrition

2.1 The Science of Nutrition

Prep Videos



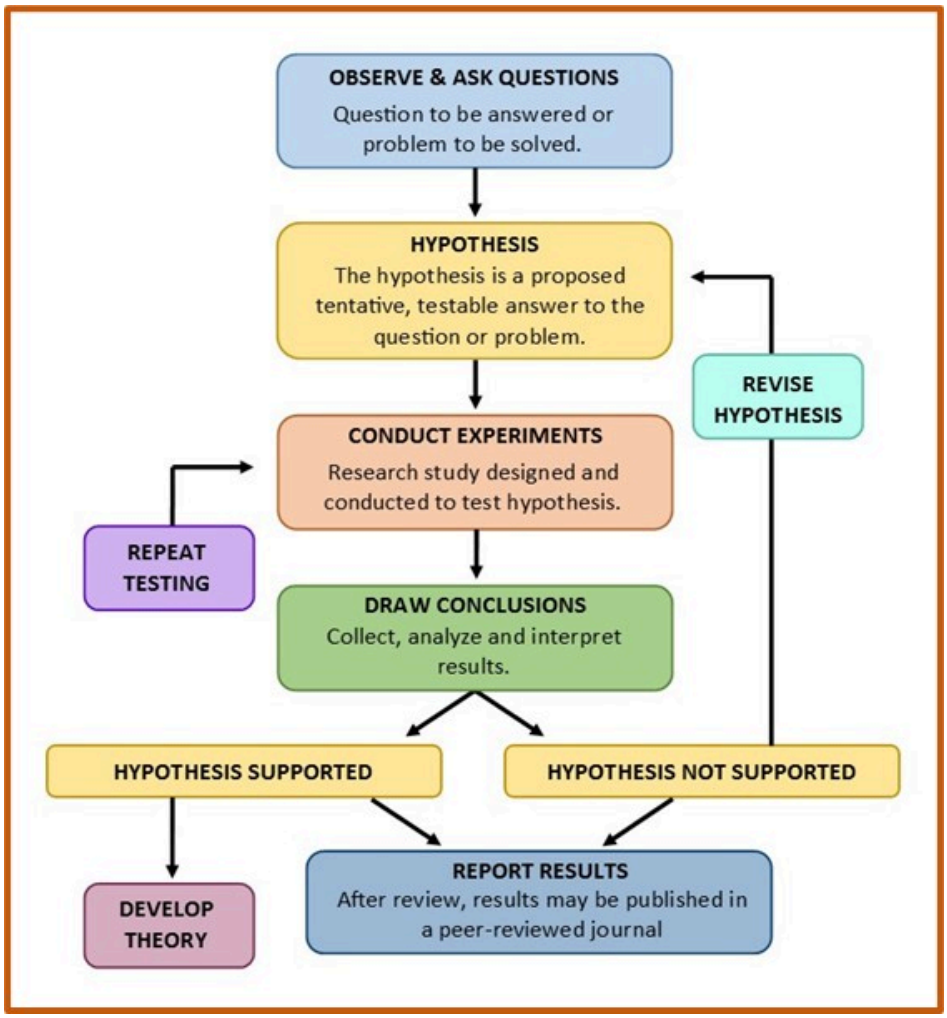
Brigham Young once taught that members of the Church seek diligently after truth: "There is no other people in existence more eager to see, hear, learn, and understand truth."[1] In today's world of constant information flow, this principle is more relevant than ever, especially when it comes to nutrition.

A quick internet search yields thousands of nutrition posts, reels, and videos. Social media is flooded with advice, opinions, and trends. But how do you know what to trust? How do you separate hype from credible, science-based guidance?

Scientific Method

Nutrition is a science grounded in the same principles as biology, chemistry, and physics. Like these disciplines, it follows the **scientific method**: observing a question, forming a **hypothesis**, testing it through research, analyzing data, and drawing conclusions. When results are consistently reproduced, they may support a scientific **theory** that explains a broader phenomenon.

The scientific process is rarely a straight line. Each new study builds on or challenges previous findings, and scientific understanding evolves over time.[2] To ensure accuracy, researchers submit their findings to peer-reviewed journals, where



The scientific method

other scientists evaluate the study's design, methodology, and conclusions before publication. This peer review process helps maintain credibility and scientific integrity.[3]

Increasingly, scientists also rely on **systematic reviews** and **meta-analyses**, which combine results from multiple studies to draw stronger, evidence-based conclusions.

Types of Scientific Research

There are several types of scientific research used to test hypotheses. These include **observational studies, clinical trials, and laboratory research.**

Observational Research

Observational studies measure and record characteristics within a group without altering their behavior. They can reveal **associations** or **correlations** but cannot determine **causation**.

A key type of observational research is **epidemiology**, which looks at patterns of health and disease in populations. Epidemiological studies help identify risk factors, guide public health strategies, and track disease trends. However, they cannot prove cause and effect. For example, if a population that eats more red meat also has higher rates of heart disease, it doesn't prove that red meat causes the disease. Other factors (like physical activity, stress, or socioeconomic status) could be involved.

While observational studies have limitations, researchers use strategies like statistical adjustments and careful study design to reduce bias. It is similar to solving a mystery by gathering clues. Even if an experiment cannot be conducted, researchers can still use logic and patterns to build a strong case. For example, they might compare people with similar lifestyles, ages, or health conditions to see if one specific factor, such as soda intake or fiber consumption, is linked to a health outcome. These techniques help make the results more reliable, even though they cannot prove cause and effect.

Experimental Clinical Trials

Clinical trials test cause-and-effect relationships by assigning participants to different groups. The **experimental group** receives a specific treatment or intervention, while the **control group** receives a **placebo** (a substance with no active ingredients).

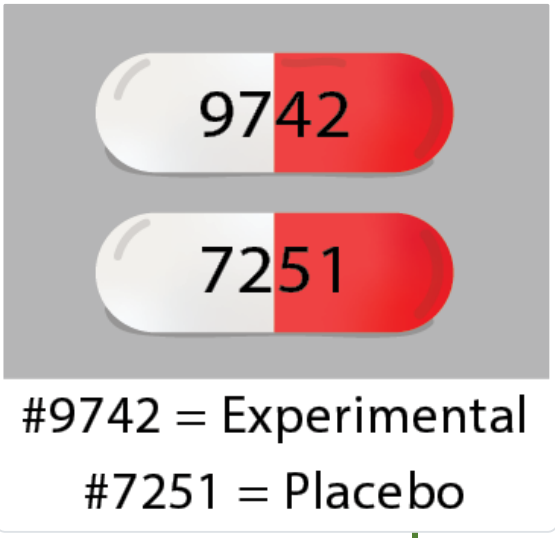
Placebos are designed to look and taste like the actual treatment. Sometimes, just believing you're receiving a treatment can lead to real changes. This phenomenon is known as the **placebo effect**.[5]

To minimize bias, researchers use **blinding**:

- In a **single-blind study**, participants don't know which group they're in.
- In a **double-blind study**, neither the participants nor the researchers know.

The most rigorous studies use **randomized, double-blind, placebo-controlled trials**. These are considered the **gold standard** in nutrition research. Randomization helps ensure that any other factors, known as **confounding variables,** are evenly distributed between groups. For example, if one group exercises more, that could affect the outcome regardless of diet.

Still, clinical trials have limitations. They are expensive, time-consuming, and often difficult to run over long periods. Participants must remain compliant with protocols. Some research questions can't be ethically studied through experimentation. For example, assigning pregnant individuals to consume alcohol would be unethical.

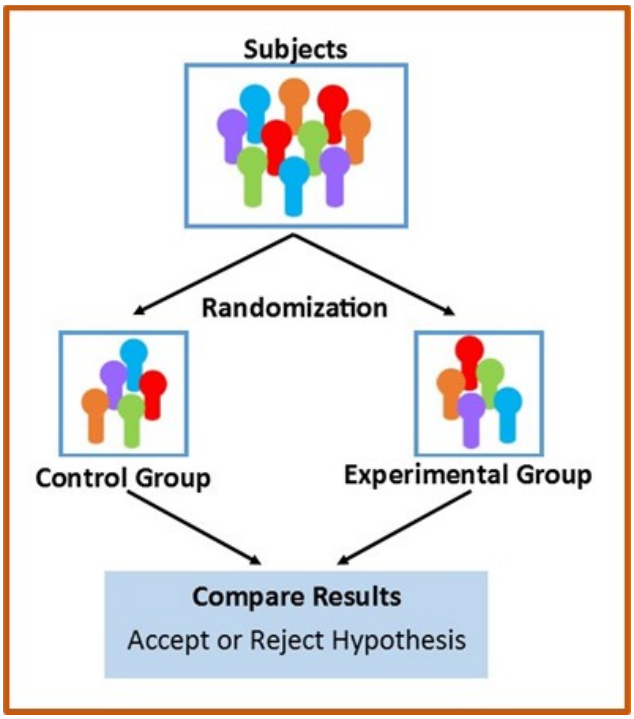


Example of coding placebo verses treatment pills. Created by AP

Laboratory Studies

Lab studies, conducted on animals or isolated cells, allow researchers to explore nutrition at a molecular level. These studies offer more control over variables and can uncover mechanisms of action ("how" a nutrient works). They are typically less expensive and faster than human trials.

However, results from lab studies do not always translate directly to humans. Findings in mice or petri dishes must be tested further in human studies before being used to shape nutrition guidelines. Newer techniques, such as using simulated digestion or computer modeling, help researchers better understand how nutrients might behave in the human body. These tools make it easier to predict real-world effects and guide future human research.



Experimental research

How Science Evolves

Science is a self-correcting process. One study rarely changes guidelines; instead, consistent evidence over time builds confidence in recommendations. It's normal, healthy, and expected for science to evolve.



A lab mouse. bPhoto by Aleksandr Gusev on Unsplash

Still, it's wise to consider **who funded a study** and **how it was conducted**. Funding from biased sources (e.g., soda companies studying sugar intake) can influence outcomes or the way results are presented. Resources like **ClinicalTrials.gov** and **Cochrane Reviews** help consumers assess transparency and quality.

Learning to critically evaluate nutrition information is a valuable skill that will benefit you throughout life. As you practice asking thoughtful questions and seeking quality evidence, you'll gain confidence in evaluating the credibility of nutrition information.

Key Takeaways

- *Nutrition is grounded in the scientific method.*
- *Observational studies can identify associations but not causation.*
- *Clinical trials, especially randomized and double-blind ones, provide strong evidence.*
- *Lab studies are helpful but must be followed by human trials.*

- *Science evolves over time. One study is not enough.*
- *Always check for funding sources, conflicts of interest, and peer review status.*

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2.2

Evaluating Strength of the Evidence from Scientific Studies

2.2 Evaluating the Strength of Scientific Evidence

Science helps us learn more about nutrition, but it does not give final answers. What we believe now may change when new and better research comes out. This does not mean we should not trust science. It just means we need to understand how to tell if nutrition information is strong and trustworthy.

What Makes Nutrition Research Strong?

What makes scientific evidence strong or reliable? How can you tell? Asking the following questions can help in determining the strength of the evidence.

1. Can the evidence be measured?

Good research uses numbers and data that can be measured and repeated. This is called **quantifiable** evidence.

- **Anecdotal evidence** is based on personal stories or opinions. This type of evidence is weak because it has not been tested in a scientific way.
- **Observational studies**, such as those in public health, look for patterns between habits and health outcomes. These studies are **moderate** in strength if they are well designed, include many people, and have results that match other similar studies.
- **Experimental studies**, like **randomized controlled trials (RCTs)**, test how a specific change (like a diet or supplement) affects people. These studies are **strong** when well designed.

Animal and cell studies can help us learn how something works, but we need to test those results in people before using them to guide nutrition advice.

2. Was the right group of people studied?

Studies are better when they include people similar to the group we are trying to help. For example, a study done to evaluate the effect of beet root powder on the endurance performance of Olympic athletes should test the product on elite athletes and not recreational or high school level athletes.

Also, larger studies usually give better results. Small studies may not show what would happen in the general population.

Type of Evidence	Strength of Evidence
Anecdotal, Opinion, Poorly Designed Study, Single Study, Small Studies	Weak to Limited
Well-designed Observational or Epidemiological Studies that have consistent results	Moderate
Well-designed, Large, Randomized, Double-blinded, Placebo-controlled, Clinical Trials that have consistent results	Strong

Evaluating the strength of the evidence

3. Were there proper controls?

Controls or regulations help to eliminate unimportant, unconnected, or confounding factors that might otherwise affect the end result of an experiment. Studies that provide strong evidence use proper controls including a control group, randomization, and double blinding to reduce or eliminate the placebo effect.

4. Did the study use proper controls?

Good studies try to remove other factors that might affect the results. They often use:

- A **control group** that does not get the treatment
- **Random assignment** so participants are chosen by chance
- **Blinding**, where the participants or researchers do not know who gets the treatment

These tools help make sure the results are caused by the treatment, not by something else.

5. Were the results interpreted fairly?

Even good studies can be misunderstood. To check how reliable a study is, ask:

- Was it reviewed by other scientists?
- Did the authors explain any limits of the study?
- Do the results match what other studies found?
- Was the study paid for by a company that might benefit from the results?

One study alone is not enough to prove something. Strong evidence comes from many studies that show the same results.

Key Takeaways

- *To make good choices about food and health, understand where the information comes from.*

- *Ask how the study was done and who was included.*
- *Check if the results are clear and repeatable.*
- *Science improves over time.*
- *We can trust findings more when many strong studies agree.*

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2.3

Tools for Evaluation

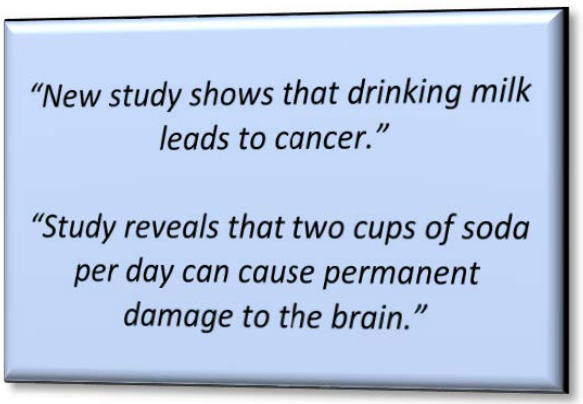
2.3 Tools for Evaluation

Elder Mark Bassett of the Quorum of the Seventy explained, "In this modern age, we have come to expect that knowledge can and should be obtained immediately; when information is not easily known or accessible, it is often dismissed or mistrusted. Because of the abundance of information, some unwittingly give more credibility to available sources with an unknown origin."[1] In today's world, where internet access is instant and information is everywhere, it is easy to be misled if you do not know how to evaluate nutrition-related information from reliable sources.

Evaluating Nutrition in the Media

It is common to see dramatic headlines about nutrition. These headlines are often exaggerated to grab your attention, but they can be misleading. No matter where you get your information, it is important to evaluate it carefully and think critically.

News organizations receive hundreds of press releases from food and supplement companies, medical groups, and research journals. These groups hope the media will share their "breaking news." But are these press releases reliable? Is the media qualified to judge if a report is accurate? How can you tell?



Examples of sensational Headlines

Here are some tips to help you evaluate nutrition news critically:

- Look for news outlets that consult independent experts to explain the findings and their relevance.
- Make sure the study is published in a peer-reviewed scientific journal. Be cautious of studies not peer-reviewed or from unreliable sources.
- Check the study methods. How long did it last? How many participants were involved? Were outcomes measured directly or based on self-report?

- Consider the study population. Were the subjects animals or humans? If human, do they share characteristics with you?
- Remember, one study does not prove or disprove anything. Reliable reports will explain how the study fits into the broader body of research.
- Ask yourself, "Does this make sense?" If a headline sounds too good to be true, it probably is. Look up the original study when possible.

Evaluating Internet Sources

Ask yourself the following questions when reviewing a health website:

WHO wrote or published the content?

- Who is the author?
- What are their credentials?
- Can you contact the author?
- Is the site backed by a reputable organization?

WHAT is the purpose of the content?

- Is the goal to inform, persuade, or entertain?
- Is the information objective or biased?
- Is it well written and free of errors?
- Are references provided?

WHEN was the information created and last updated?

- Does the site indicate when it was published and most recently revised?
- Is the information current?

WHERE is the content hosted?

- What is the domain (e.g., .com, .edu, .gov, .org)?
- What does the extension suggest about the source?

WHY should you trust this site?

- Is the content verifiable, up-to-date, and relevant to your needs?
- Is it trying to sell something?
- Why is this source better than another?

WHO?	**WHO wrote/published the information on the site?** • Who is the author? • Does the author provide contact information? • What are the author's credentials or qualifications? • Is the site created or sponsored by a reputable organization? • Who runs and pays the website?
WHAT?	**WHAT information and resources does the site provide?** • What is the site's purpose: to persuade, inform, or entertain? • Is the information subjective (biased or opinionated), objective, or mixed? • Does the site provide thorough coverage of the topic? • Is the information well written? Are there misspellings or grammatical errors? • Does the site provide references?
WHEN?	**WHEN was the site created and last updated?** • Does the site indicate when it was first created and last updated?
WHERE?	**WHERE does the site come from or "live"?** • What is the extension in the URL (i.e. .com, .net, .edu, .gov, .org)? • What does the extension tell me about the source of the site? • Is there anything more current?
WHY?	**WHY should I use this site?** • Why is this information useful for my purpose? • Is the information verifiable, in-depth, and up-to-date? • Why is this page or site better than another? • Is the site trying to sell something?

The internet offers quick access to nutrition information, and about 60 percent of U.S. adults use it to search for health topics. [2] Social media and AI tools also provide fast answers but can spread both accurate and misleading content. Unlike peer-reviewed sources, most online content is not reviewed before publication. Some is written by experts, but much is not. This means it is your responsibility to assess quality and accuracy. Asking WHO, WHAT, WHEN, WHERE, and WHY can help you determine if the source is trustworthy.

Trustworthy Sources

With so much information available, it helps to know where to turn for reliable, consistent nutrition advice.

Finding a Nutrition Expert



New graduate. Photo by Chichi Onyekanne on Unsplash.

Who should you trust for nutrition advice? Not all health professionals are equally qualified. Many receive little formal training in nutrition. Only a **Registered Dietitian (RD)** or **Registered Dietitian Nutritionist (RDN)** has the education and supervised practice required by the Accreditation Council for Education in Nutrition and Dietetics (ACEND).[3]

Most students earn a bachelor's degree in dietetics or nutrition and dietetics, which includes the required coursework to receive a verification statement (a formal document from an ACEND-accredited program confirming eligibility to begin supervised practice or sit for the RDN exam). With that verification and completion of supervised practice hours, they may pursue a master's degree in any field to become eligible to take the national RDN credentialing exam. Students who earned a bachelor's degree in a non-nutrition field typically enter a coordinated master's program that combines both the ACEND-accredited coursework and the supervised practice experience needed for RDN eligibility. While all new RDNs must now hold a master's degree, some currently practicing dietitians were credentialed under previous standards that required only a bachelor's degree.

Others may call themselves "nutritionists," but this title is not regulated and may be used by individuals who have taken few or no accredited courses and often lack supervised practice. As a consumer, it is important to seek guidance from qualified, well-trained professionals such as RDNs when looking for reliable nutrition information and advice.



Registered dietitian nutritionist working one-on-one with a client. Photo by Christina @ wocintechchat.com on Unsplash.

RDNs work with patients and clients to provide personalized guidance on making healthy dietary changes that can help prevent or treat disease. They are required to participate in continuing education to stay current in the rapidly advancing field of nutrition and science. You will find RDNs working in a wide range of settings, including hospitals, long-term care facilities, other health care centers, schools and universities, community and government agencies, businesses, collegiate and professional athletic teams, food companies, and private practice.

Reputable Websites and Organizations

What about reputable internet sources? Websites with addresses ending in .gov (government agencies), .edu (educational institutions), or .org (nonprofit organizations) are generally considered more reliable and credible. In contrast, sites ending in .com (commercial) or .net (network) should be approached with caution. The organizations and websites listed below are trusted sources for accurate, regularly updated nutrition information.

Reputable Websites	Sponsoring Organization	Website Link
Food and Nutrition Center	U.S. Department of Agriculture (USDA)	https://www.nal.usda.gov/fnic
healthfinder.gov	U.S. Department of Health and Human	https://healthfinder.gov/
Nutrition.gov	USDA and HHS	https://www.nal.usda.gov/fnic
Centers for Disease Control and Prevention	Center for Disease Control and Prevention (CDC)	http://www.cdc.gov/
National Institute of Diabetes and Digestive and Kidney Diseases	U.S. Department of Agriculture (USDA)	https://www.niddk.nih.gov/
The Academy of Nutrition and Dietetics	U.S. Department of Agriculture (USDA)	http://www.eatright.org/
Dietitians of Canada	U.S. Department of Agriculture (USDA)	http://www.dietitians.ca/
Health Canada	Health Canada	https://www.hc-sc.gc.ca/index-eng.php
American Heart Association	American Heart Association (AHA)	www.heart.org
American Cancer Society	American Cancer Society (ACS)	https://www.cancer.org

Reputable nutrition websites and organizations

Federal Trade Commission

What should you do if you find an online nutrition-related scam? Should you just ignore it? Instead of keeping it to yourself, consider filing a complaint with the **Federal Trade Commission (FTC)**. The FTC is the United States' consumer protection agency and works to prevent fraud and scams. They investigate complaints about false or misleading advertising and share this information with law enforcement agencies for further action.

Key Takeaways

- *Be skeptical of sensational headlines and one-off studies.*
- *Critically evaluate all online information using the "5 W's."*
- *Seek out credentialed experts for reliable nutrition advice.*
- *Rely on reputable sources for general nutrition information.*
- *Report fraudulent claims to the appropriate authorities.*

References (see below)

1. Bassett WM. For our spiritual development and learning.The Church of Jesus Christ of Latter-Day Saints website. https://www.churchofjesuschrist.org/study/general-conference/2016/10/for-our-spiritual-development-and-learning?lang=eng. Accessed October 28, 2016.
2. Fox S, Duggan M. Health Online 2013. Pew Research Center's Internet and American Life Project website. http://www.pewinternet.org/2013/01/15/health-online-2013. Accessed December 8, 2016.
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3

Chapter 3: Assessing Nutrient Intake

Chapter 3: Assessing Nutrient Intake

Determining if dietary intake is adequate or not can be approached from two different points of view. The amount of the individual nutrients in a diet can be determined and compared to recommendations, or the overall types and amounts of the different food groups eaten can be quantified and assessed. Each of these approaches will be explained in this section of the material.

3.1. Food Databases and Food Labels

3.2. Dietary Reference Intakes (DRI's)

3.3. Variety, Moderation and Balance.

3.4. 2020-2025 Dietary Guidelines for Americans

3.5. Using Choose MyPlate to Evaluate Food Intake

3.6. Translating Principles to Practice

3.1

Food Databases and Food Labels

3.1 Food Databases and Food Labels

People often have questions about the nutrient content of the foods they eat. For example, there has been growing attention on ensuring adequate vitamin D intake, especially for individuals living in northern regions where sunlight is not strong enough year-round to support the body's natural production of vitamin D in the skin. Others may be concerned about iron, particularly if they are at risk for anemia due to low intake or high losses. These types of concerns can lead people to examine the nutrient content of their food choices more closely. Learning how to read food labels and use food databases can help answer these questions.

Food Databases

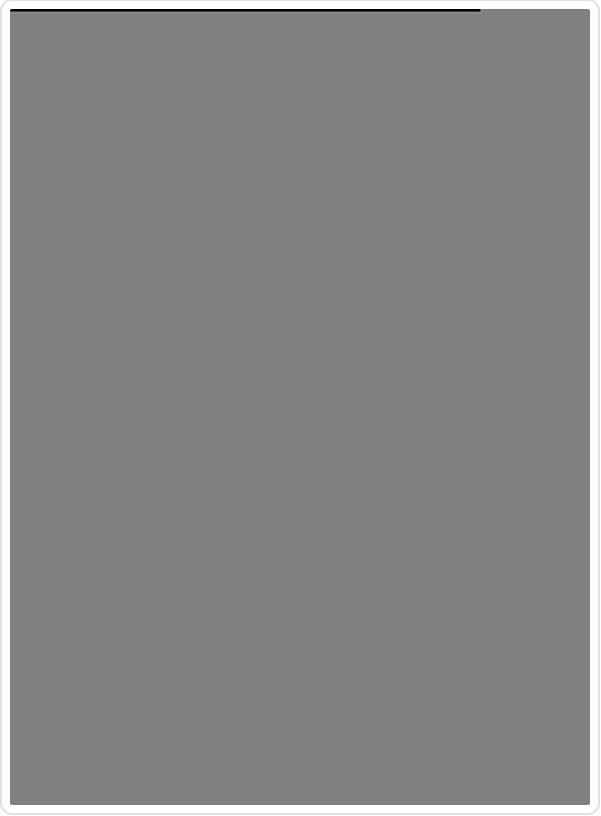
Food databases allow a user to look up nutrient content for most common foods. Typically, all that is required is to enter the name of the food in a search menu, and a list of foods that fit the description are displayed. Once you selected the most appropriate option the nutrient content of that food is displayed.

For example, imagine you live in Northern Idaho and are concerned about your vitamin D levels in the winter. You have heard that mushrooms provide vitamin D and wonder how they compare to vitamin D fortified milk (especially since you do not like milk but love mushrooms). You want to know if eating 1 cup of cooked, sliced mushrooms is similar to drinking a glass of milk. A nutrient database is an excellent tool for questions like this. You could search for "mushrooms," select the specific type, and view the nutrient composition for a set amount. You could then do the same for milk and compare the vitamin D levels. You would find that mushrooms do not provide nearly as much vitamin D as fortified milk. Not all food databases are the same; they may differ in the types of foods listed and the number of nutrients reported for each food.

Food Labels

The **food label** does not provide a comprehensive list of nutrients in food like a food database, but can be a very useful tool if a person knows how to use it. In the United States, the Nutrition Labeling and Education Act (NLEA) passed in 1990 and came

into effect in 1994. As a result, all packaged foods sold in the United States and Canada must have nutrition labels that accurately reflect the contents of the food products. There are several nutrients that must be listed on the food label. They include: total Calories, total fat, saturated fat, cholesterol, total carbohydrates, dietary fiber, total sugars, added sugars and vitamin D, calcium, iron and potassium. The generic food label in Figure 3.1 shows these items as they currently appear on a food label (represents the nutrition facts for 2/3 cups of granola).[1]



There are other types of information that are required by law to appear somewhere on the consumer packaging. These include:

- Name and address of the manufacturer, packager, or distributor
- Statement of identity, what the product actually is
- Net contents of the package: weight, volume, measure, or numerical count
- Ingredients, listed in descending order by weight

The focus of this discussion will center on the basics of how to read a food label, how to interpret and use the Daily Values, and how to interpret the ingredient list and nutrient content claims.

Reading the Label

The nutrient content listed on a food label is based on the serving size shown at the top of the Nutrition Facts panel. In 2016, the food label was updated, and serving sizes were adjusted to better match typical American eating habits. In many cases, serving sizes increased to reflect how much people actually eat today. For example, a serving of soda increased from 8 ounces to 12 ounces, and a serving of ice cream went from 1/2 cup to 2/3 cup.

The granola label in Figure 3.1 shows that a 2/3 cup serving has about 230 calories. All other nutrients listed also correspond to this 2/3 cup serving size. If you eat more than the serving size, you need to multiply the values on the label by the number of servings you ate. For example, if you ate 1 1/3 cups of granola (twice the serving size), you consumed 460 calories. The amounts of all other nutrients would also double. Additional guidelines on serving sizes are shown in Figures 3.2 and 3.3.[2]



Nutrition Facts

8 servings per container

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

Amount per serving

Calories **230**

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

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

Figure 3.1: Granola food label. Typical items included on a standard food label (2/3 cup granola)



Shopper reading labels. Photos by Nataliya Vaitkevich on Pexels.



Figure 2.2: Designation of serving sizes for products that contain 2 to 3 servings

Additional Info

If a product contains between one and two servings, the Nutrition Facts label will list the nutrition information for the entire package. For example, a 20-ounce bottle of soda will show values based on all 20 ounces, even though a standard serving size is 12 ounces. This is because people usually consume the whole container in one sitting.



Nutrition Facts

3 servings per container

Serving size 2/3 cup (87 grams)

	Per 2/3 cup		Per container	
Calories	**170**		**520**	
	% DV*		**% DV***	
Total Fat	**14%**	9g	**43%**	28g
Saturated Fat	**30%**	6g	**90%**	18g
Trans Fat		0g		0g
Cholesterol	**13%**	40mg	**40%**	120mg
Sodium	**2%**	50mg	**7%**	160mg
Total Carbs	**6%**	19g	**19%**	56g
Dietary Fiber	**0%**	0g	**0%**	0g
Sugars		19g		56g
Added Sugars		15g		45g
Protein		4g		12g
Vitamin D	0%	0mcg	0%	0mcg
Calcium	11%	110mg	34%	338mg
Iron	0%	0mg	0%	0mg
Potassium	5%	165mg	14%	500mg

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

Figure 3.3: Designation of serving sizes for products that contain 2 to 3 servings

Additional Info

For products that contain 2 to 3 servings, a dual-column label may be required. This format shows nutrition information per serving and per container to help consumers make more informed choices.

Daily Values (DV)

On the Nutrition facts panel, the serving size is followed by the number of calories per serving and then a list of selected nutrients. The "%DV" **(Percent Daily Value)** is shown on the far right side. This number tells you how much one serving contributes to the recommended daily amount of that nutrient for someone eating a 2,000-calorie diet.

For some nutrients, the daily value represents a maximum amount you should not exceed (like saturated fat, added sugars, and sodium). For other nutrients, it is a target to reach (like vitamin D, calcium, iron, potassium, and fiber).

As a general rule, a %DV of 5 or less is considered low, and 20 or more is considered high. Aim for a low %DV in nutrients you want to limit, and a high %DV in nutrients you want to get enough of. The goal is to stay under 100% for nutrients you should

limit and to reach about 100% for nutrients you need more of throughout the day.

Dietary Component	Daily Value	Dietary Component	Daily Value
Total Fat	78 g	Niacin	16 mg NE
Saturated Fat	20 g	Vitamin B6	1.7 mg
Cholesterol	300 mg	Vitamin B12	2.4 mcg
Total Carbohydrate	275 g	Biotin	30 mcg
Added Sugars	50 g	Pantothenic Acid	5 mg
Dietary Fiber	28 g	Calcium	1,300 mg
Protein	50 g	Phosphorous	1,250
Sodium	< 2300 mg	Iodine	150 mcg
Potassium	4,700 mg	Iron	18 mg
Vitamin A	900 mcg RAE	Magnesium	420 mg
Vitamin C	90 mg	Copper	0.9 mg
Vitamin D	20 mcg	Zinc	11 mg
Vitamin E	15 mc alpha-tocopherol	Chloride	2,300 mg
Vitamin K	120 mcg	Manganese	2.3 mg
Folate	400 mcg	Selenium	55 mcg
Thiamin	1.2 mg	Chromium	35 mcg
Riboflavin	1.3 mg	Molybdenum	45 mcg
g=gram, mg=milligram, mcg=microgram IU=international unit, DFE=Dietary Folate Equivalents, NE=Niacin Equivalents			

Table 1: DVs based on a caloric Intake of 2,000 Calories (for adults and children four or more years of age)[2]

Determining the Percent Daily Value

The Percent Daily Values (%DV) for energy-yielding nutrients, such as carbohydrates, sugars, protein, and fat are based on recommended intake levels for a 2,000-calorie diet. Daily Values for other nutrients are established to promote optimal health. For example, the Daily Value for added sugars is set at a maximum of 50 grams per day. Table 1 presents the Daily Values used for nutrition labeling purposes.

Ingredient List

It is required that the ingredients be listed by weight from highest to lowest. In the following product, the predominant ingredient is whole wheat flour. Can you guess what this product is?

Whole Wheat Flour, Water, Wheat Gluten, Sugar, Yeast, Vegetable Oil, Salt, Preservatives (Calcium Propionate, Sorbic Acid), Natural Flavors, Monoglycerides, Monocalcium Phosphate, Soy Lecithin, Citric Acid, Grain Vinegar, Sesame Seeds.

If you guessed “bread” you are correct. You can tell that it is whole wheat bread, because the first ingredient is whole wheat flour.

Ingredient lists can also help you evaluate a product’s nutrient density. Consider the following beverages:

Product A Ingredients: Apple, grape and pomegranate juice from concentrate, fruit and vegetable juices (for color), blueberry juice from concentrate, natural flavors, raspberry juice from concentrate, modified gum acacia, vitamin C, citric acid.

Product B Ingredients: Filtered water, sugar, apple juice concentrate, citric acid, strawberry juice concentrate, natural flavor.

Which one appears more nutrient dense?

Both products contain juice, but product A is clearly the more nutrient-dense choice. It is made of 100% fruit juices with no added sugars. Product B has added sugar as the main ingredient after water, and although it contains some fruit juice, it is much lower on the ingredient list.

However, there is more to the story. While product A is more nutrient-dense, its producers have been criticized for misleading advertising. The product is labeled as pomegranate and blueberry juice, yet neither of these juices makes up a significant part of the product. According to The New York Times, pomegranate and blueberry juices together only contribute 0.5% of the total juice content.[3]

By correctly assessing the ingredient list, a savvy consumer would have been able to determine this on their own. As a person’s understanding increases they become better able to be agents that act instead of being acted upon.

Claims on Labels

In addition to requiring certain nutrients and ingredients on food labels, the FDA regulates **nutrient content claims**. For example, a manufacturer cannot claim that a product is 'fat-free' or 'low-fat' if it is in fact not. A product cannot be labeled 'fat-free' or 'low-fat' unless it meets specific criteria. 'Low-fat' means 3 grams of fat or less per serving; 'low-sodium' means fewer than 140 milligrams of sodium; and 'low-cholesterol' means fewer than 20 milligrams of cholesterol and 2 grams of saturated fat per serving. (see Table 2.)

Table 2 Term	Explanation
Free	This term means that a serving of the product contains a nutritionally insignificant amount of calories, fat, saturated fat, cholesterol, sodium, or sugars. For example, a product labeled **sugar-free** or **fat-free**

Table 2 Term	Explanation
	contains less than 0.5 grams per serving. A **sodium-free** product contains less than 5 milligrams per serving.
Low	This term is used for products that contain a limited amount of calories, fat, saturated fat, cholesterol, or sodium. For example, a product labeled **low fat** must contain 3 grams of fat or less per serving. A **low sodium** product must have 140 milligrams of sodium or less per serving.
High/Excellent	Indicates that a serving of the product provides **20% or more of the Daily Value (DV)** for a given nutrient
Good Source	Indicates that a serving of the product provides **10% to 19% of the Daily Value (DV)** for a specific nutrient
Reduced	Indicates that a product contains **at least 25% less** of a specific nutrient, such as calories, fat, saturated fat, cholesterol, added sugars, or sodium when compared to a similar reference food. For example, a **reduced-sodium soy sauce** would have 25% less sodium than regular soy sauce

Table 2: Common label terms defined [4]

Health Claims

We often hear about specific nutrients or food products that are said to support health or help prevent disease. A health claim is a statement that links a food or nutrient to a reduced risk of developing a disease. For example, a food label might say "may reduce the risk of heart disease."

All health claims must be evaluated and approved by the FDA before they can appear on food packaging. Before the Nutrition Labeling and Education Act (NLEA) was passed, products making such claims were considered drugs rather than foods.

Health claims must be supported by scientific evidence, and there are strict rules about how they can be presented. For example, they cannot claim to cure or treat a disease. These regulations help prevent false or misleading statements on food labels. (For more information, visit FDA.gov.)

Food Labels - An international perspective

The purpose of a food label is to help consumers make good food choices. Food labeling laws are designed to protect consumers from misleading information and ensure labels are consistent and easy to understand. Each country creates its own labeling guidelines based on what it believes is most important for its people.

Food labeling laws and how strictly they are enforced can vary widely from country to country. Labels may also differ within a country depending on the type of food product, and some foods may not have labels at all. These differences show the challenges faced by international food companies selling products worldwide. Even if the product itself stays the same, the food label must be adapted to meet each country's regulations. You can see an example of this by comparing U.S. and Nigerian Coca-Cola labels in Figure 3.4.



Figure 3.4: Comparison of Coca-Cola (500 mL) food labels from the United States and from Nigeria

As you compare the two labels, see (table 3) for a few things to pay attention to:

	United States Food Label	Nigerian Food Label
Amounts (both are about a 16 ounce serving - but the units are different)	16.9 fluid ounces (1.06 pints) 500 ml	50 cl - 50 cl is 500 ml CL stands for centiliters and is ten times larger than a milliliter (mL).
Energy (Calorie)	Calories	Kilojoules and kcals
Nutrition facts based on	One bottle (500 ml)	10 cl (100 mL) - to compare to the US bottle you need to multiple the values by 5
Recommended amounts/limits	Daily Value (DV)	Guideline Daily Amounts (GDA)- based on 25 cl
Added sugars	Listed	Not listed
Ingredients	Listed	Listed

Table 3: Comparison of Coca-Cola (500 mL) food labels from the United States and from Nigeria

Here are a few fun things to look for:

- When you compare the two products, you may notice they are not exactly the same (check the ingredient list). The Nigerian product is a specialty version with reduced sugar and contains the artificial sweetener sucralose. This version is not commonly found in the U.S. The American product is the standard Coca-Cola. Both versions are sold in Nigeria.
- The Nigerian label uses Guideline Daily Amounts (GDAs) to show nutrient content, while U.S. labels use Daily Values (DVs).
- In Nigeria, energy is listed in both kilojoules (kJ) and kilocalories (kcal). In the U.S., energy is shown as Calories with a big "C," which actually refers to kilocalories.

Food labels can help guide food choices. However, in many countries where people rely on fresh foods from local markets, there are often few or no food labels available. This is similar to shopping at a farmers market in the U.S., but on a much larger scale. In these cases, following the principles of variety and balance is a good approach to choosing healthy foods.



Food Market in Peru

Key Takeaways

- *Food databases offer detailed nutrient information.*
- *The food label is a key tool for making quick choices.*
- *Pay attention to serving size and the Daily Value (%DV).*
- *Read the ingredients list and nutrient claims carefully.*
- *Labeling laws can vary significantly by country.*

References (see below)

- 1. U.S. Food and Drug Administration. Changes to the Nutrition Facts Label. U.S. Department of Health and Human Services website. https://www.fda.gov/food/food-labeling-nutrition/changes-nutrition-facts-label. Updated March 11, 2024. Accessed June 2025.
- 2. Industry Resources on the Changes to the Nutrition Facts Label: Updated Daily Values Final Rule. U.S. Food and Drug Administration Website. https://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm513734.htm Updated March 1, 2018
- 3. Liptak, A. Coke Can Be Sued by Rival Over Juice Claim, Court Says. The New York Times. June 12, 2014. http://www.nytimes.com/2014/06/13/business/supreme-court-says-coca-cola-can-be-sued-by-Pom-Wonderful.html?_r=0.
- 4. Guidance for Industry: A Food Labeling Guide. U.S. Food and Drug Administration Website. http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm2006828.htm. Published January 2013. Updated November 14, 2017.

3.2

Dietary Reference Intakes (DRI’s)

3.2 Dietary Reference Intakes (DRI’s)

The **Dietary Reference Intakes** (DRIs) are evidence-based standards developed by the Institute of Medicine to evaluate the nutrient intake of healthy individuals. Nutrient values from food labels or databases are only meaningful when compared to these standards. The DRIs include several categories: **Recommended Dietary Allowances** (RDA's), **Adequate Intakes** (AI's), **Tolerable Upper Intake Levels** (UL's), **Acceptable Macronutrient Distribution Ranges** (AMDR's), **Estimated Energy Requirements** (EER), and **Estimated Average Requirements** (EARs). This section will focus on RDA's, AI's, EAR's, and U'Ls (see Figure 3.5); AMDRs and EERs will be discussed later.

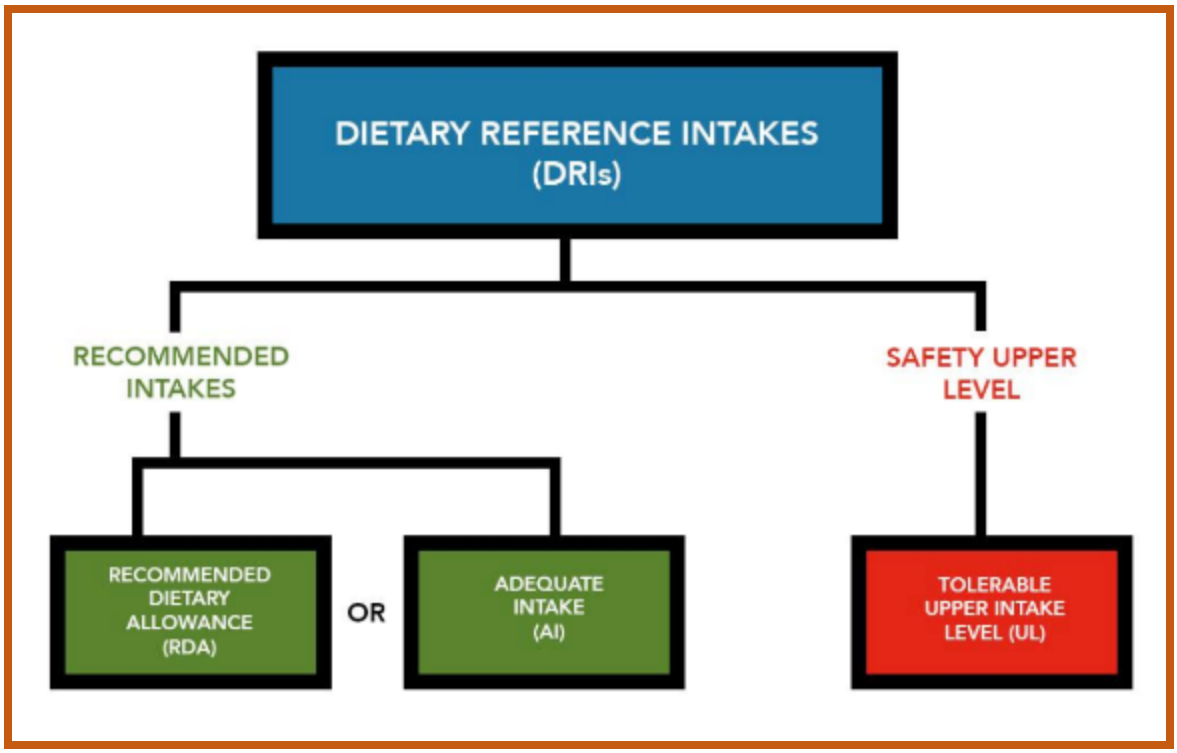


Figure 3.5: The dietary reference Intakes Includes recommended daily intakes (RDA's) and adequate intake (AI's) as well as intake levels that can be detrimental to health (tolerable upper intake level or UL's)

Establishing the recommendations

To establish dietary recommendations for each essential nutrient, experts begin by reviewing current, peer-reviewed research. Researchers use standardized methods to determine nutrient needs, which may be based on factors such as nutrient intake compared to losses, blood levels of the nutrient, or more complex assessments, such as measuring the activity of an enzyme that depends on the nutrient.

In the case of calcium, for example, blood levels do not accurately reflect intake. Therefore, recommendations were based in part on the amount needed to optimize bone mineral density.

Nutrient requirements are typically established for specific age and gender groups. However, even within these similar groups, individual needs vary due to natural biological diversity. For instance, if vitamin A requirements were measured in a large group of women ages 19 to 30, the results would form a distribution (see Figure 3.6). The amount that meets the needs of 50 percent of the group is known as the **Estimated Average Requirement** (EAR)

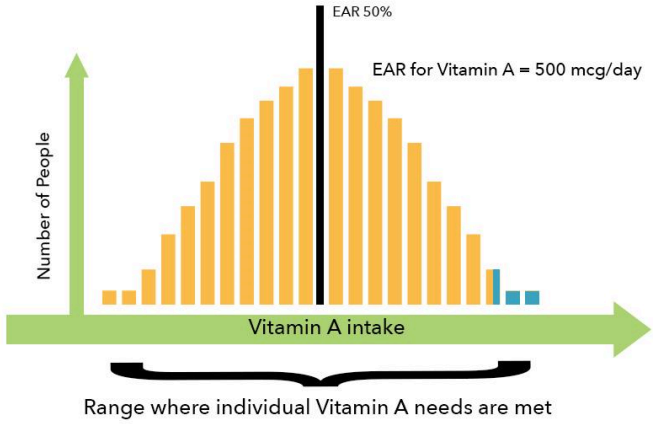


Figure 3.6: A hypothetical representation of Vitamin A needs of a group of women ages 19-30

If we think about it, using the Estimated Average Requirement (EAR) as a recommended intake for the general population would be a mistake. For example, the EAR for vitamin A in females aged 19 to 30 is 500 micrograms per day. If everyone aimed for that amount, half the population would still be getting too little of the nutrient.

To avoid this, the **Recommended Dietary Allowance** (RDA) is set higher. It is typically calculated as two standard deviations above the EAR, which is enough to meet the needs of 97 to 98 percent of the population. This more inclusive recommendation is what most people should aim for (see Figure 3.7).

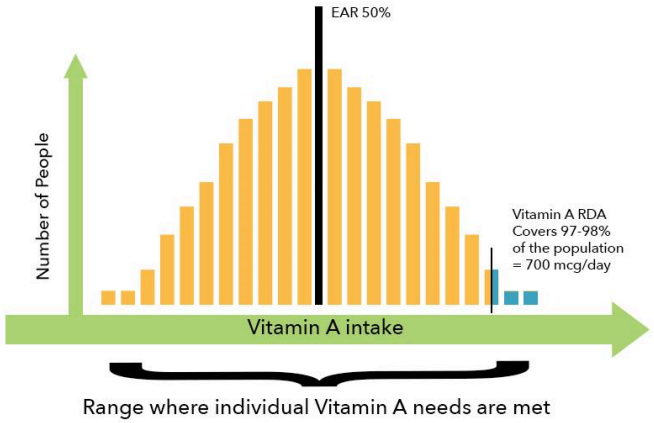


Figure 3.7: Setting RDA's

The RDA for vitamin A for a female 19-30 years of age is 700 mcg/day, 200 mcg higher than the EAR. For some of the nutrients, insufficient consistent scientific data is available to set an EAR and associated RDA. In those cases, a recommended intake is still provided, but it is labeled as an **Adequate Intake** (AI), instead of an RDA. It represents an estimation of dietary need based off typical intakes of healthy people.

Establishing recommended intake levels is not the only concern that needs to be addressed when discussing nutrient intake levels; excessive consumption of many of the vitamins and minerals can be harmful. Some have only mild effects; others can be lethal if excessive amounts are consumed. If a nutrient has a known toxicity, a **Tolerable Upper Intake Level** (UL) is set. For example, vitamin A for women 19-30 has a UL of 3000 mcg/day (remember the RDA was 700 mcg/day for women 19-30). It is typically very difficult to exceed the UL by eating food; overdoses of vitamins and minerals most often occur through

supplementation. The UL represents the highest level of a nutrient that is likely to pose no adverse health effects. If a nutrient does not have a UL set, it is not necessarily safe to consume in large amounts. Such practices are how we discovered that some nutrients that did not have a UL needed one. Figure 3.8 correctly displays the appropriate view of most vitamin and minerals. Danger lurks on each end of the spectrum, too much or too little of a nutrient can be harmful. The idea that more of something good is always better, is not the case when considering vitamin and mineral intake.

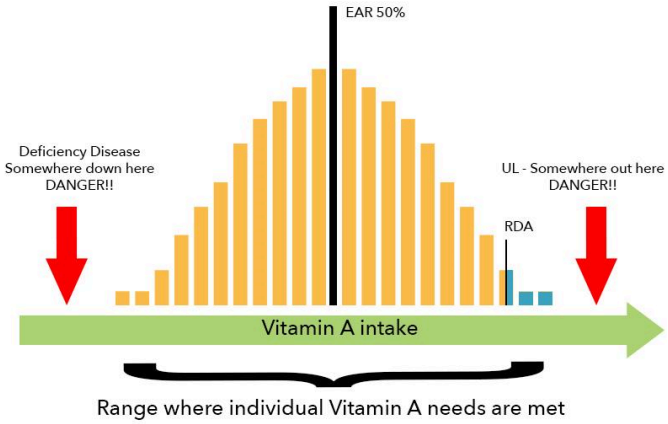


Figure 3.8: Setting the tolerable upper intake level (UL)

In summary, remember that the RDA's do not reflect your personal need; to find out your personal need, you would need to be tested individually. The recommendations are set generously, so if your intake reaches the RDA (or AI) it is most likely your intake is just fine. The DRIs are also not appropriate for people who are ill or malnourished, even if they were healthy previously.

The United states and Canada share the same Dietary Reference Intakes. Some other countries have also established dietary intake guidelines that are unique to their country. Typically, you can expect to see categories similar to those observed in the US guidelines such as RDA's, AI's, UL's and AMDR's. RDA recommendations are typically given by age and gender. Table 4 shows a comparison of the recommended intakes for a few selected nutrients (RDA's) from the USA, Japan, the Philippines and the United Kingdom.

	Vitamin (µg/day)	Vitamin C (mg/day)	Iron (mg/day)	Folate (xx/day)	Calcium (mg/d)
USA	900	90	8	400	1000
Japan	850	100	7	240	800
Philippines	700	70	12	400	750
United Kingdom	700	40	8.7	200	700

Table 4: Adult Male Recommended Intakes from selected countries created by AP [6,7,8,9]

Adult Female-Recommended Intakes

	Vitamin A	Vitamin C	Iron (mg/day)	Folate	Calcium

	(µg/day)	(mg/day)		(µg/day)	(mg/d)
USA	**700**	**75**	**18**	**400**	**1000**
Japan	650	100	6 Not menstruating 10.5 Menstruating	200	650
Philippines	600	60	28	400	750
United Kingdom	600	40	14.8	200	700

Table 5: Adult Female Recommended Intakes from selected countries [6,7,8,9]

Key Takeaways

- *DRIs are science-based standards for nutrient intake.*
- *The RDA is set to meet the needs of most people.*
- *More is not always better for vitamins and minerals.*
- *Nutrient recommendations vary by age, gender, and country.*

References (see below)

- 6. United States Department of Health and Human Services. National Institute of Health. Nutrient Recommendations: Dietary Reference Intakes. Accessed 5/26/2020 https://www.ncbi.nlm.nih.gov/books/NBK56068/table/summarytables.t2/?report=objectonly and https://www.ncbi.nlm.nih.gov/books/NBK545442/table/appJ_tab3/?report=objectonly
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3.3

Variety, Moderation and Balance.

3.3 Variety, Moderation and Balance.

Food labels, nutrient databases, Daily Values and the DRI's are used to evaluate the nutrient content of foods. Next, tools that are available to evaluate intake from a food point of view will be addressed; they include the Dietary Guidelines for Americans and its visual representation,

Choose MyPlate. Before starting this discussion, it will be important to understand the principles of variety, moderation and balance.

A healthy diet can best be achieved by selecting nutrient dense foods while following the principles of variety, moderation, and balance.

Variety

The foods we eat are typically grouped into 6 major categories: protein, grains, fruits, vegetables, dairy and oils. The principle of variety refers to consuming foods from each of the food groups on a regular basis. The principle of variety is represented by the United States Department of Agriculture's "MyPlate" eating pattern (see Figure 3.9). The MyPlate visual illustrates the importance of choosing foods from all of the food groups on a regular basis, and will be discussed in more detail later.

It is also important to apply the principle of variety within food groups as well. For instance, a person may choose to have a vegetable at every meal, but may only select between potatoes and corn. The principle of variety in the vegetable group would be best met by regularly choosing vegetables with a variety of colors. The different colored vegetables typically contain different essential nutrients and different phytochemicals.

In the United States wheat is the primary grain product in our food supply. We often overlook other healthy whole grains such as barley, quinoa, rye and buckwheat. Optimal health benefits come from applying the principle of variety when choosing grains as well. Plus, part of the fun of eating is finding a new healthy food you enjoy!

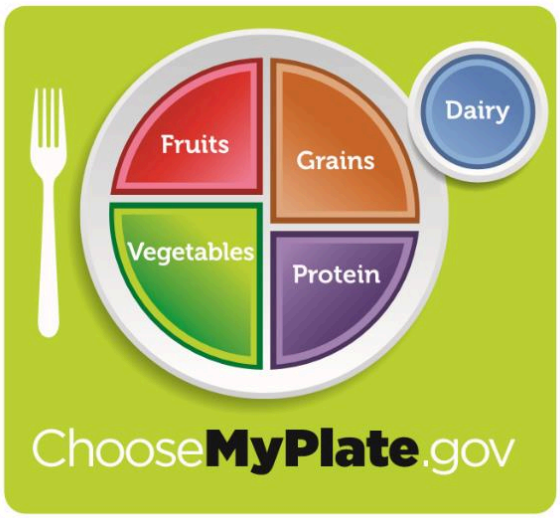


Figure 3.9: The United States Department of Agriculture's "MyPlate" eating pattern emphasizes choosing foods from each of the food groups on a regular basis[10]

Moderation

The principle of **moderation** is applied by not eating to the extremes, neither too much nor too little. In places where food is abundant and easily accessed, overconsumption is a common problem. Overconsumption of calories, saturated fats, added sugars, sodium, and alcohol have been highlighted to Americans as dietary areas of particular concern.[10]

Balance

The principle of **balance** brings eating into perspective. Eating French fries, cake, and ice cream each night with dinner will lead to health complications and doesn't match the principle of variety or moderation. The principle of balance teaches that it is okay to choose a dinner like that occasionally, and when a less nutrient dense dinner is selected, your breakfast and lunch might be carefully selected with extra nutrient dense choices from the appropriate groups to balance out your intake.





The principle of balance is practiced when the selection of foods complement each other and manage overall caloric and nutrient intake. Photo 1 by Jacopo Maiarelli on Unsplash. Photo 2 by Robin Stickel on Pexels.

Key Takeaways

- *A healthy diet is based on three core principles.*
- *Variety involves eating foods from all major food groups.*
- *Moderation is about avoiding extremes.*

- *Balance means making thoughtful food choices over time.*

References (see below)

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

3.4

2020-2025 Dietary Guidelines for Americans

3.4 2020-2025 Dietary Guidelines for Americans

The U.S. Departments of Health and Human Services (HHS) and of Agriculture (USDA) are required, by law, to publish evidence based nutrition and dietary recommendations every five years. These recommendations are called the Dietary Guidelines for Americans. This publication promotes healthy eating and exercise practices to help support a healthy weight and reduce the risk of chronic disease throughout the lifespan.

The Dietary Guidelines is designed to help all Americans consume a well-balanced and adequate diet. The information in this report is used to make public health education materials, policies and programs. The most current publication, the 2020-2025 Dietary Guidelines for Americans, emphasizes four key elements to help Americans eat well and help prevent disease.[10]

1. Follow a Healthy Eating Pattern at Every Life Stage

Achieving a healthy eating pattern can have an immediate effect on our health as well as minimize our risk for chronic disease later in life and may even reduce health risks of future generations. A healthy eating pattern is flexible and takes into account individual calorie needs, personal preferences, time and budget. It is best to include healthy choices in each of the food groups within a healthy eating pattern – vegetables, fruits, lean protein, low-fat dairy and grains – especially whole grains, and oils. Healthy eating patterns limit calories from added sugar and saturated fats and reduce sodium intake (see Figure 3.10).

Healthy eating starts at birth with exclusive consumption of breastmilk, if possible, or iron fortified formula for about the first six months of life. Vitamin D supplements should be provided for breastfed infants. Solids (soft and pureed foods) and other beverages are introduced at about age 6 months. Healthy eating patterns established in the first year of life can then be maintained through the life span. Nutrient needs will vary during different life stages, but the type of food and beverage choices that are best for health remain similar.



Figure 3.10: Components of a healthy eating pattern has both variety. Photo

2. Customize and Enjoy Nutrient-dense Food and Beverage Choices to Reflect Personal Preferences, Cultural Traditions, and Budgetary Considerations

No matter a person's age, race, ethnicity or health status, almost everyone can benefit from a change in their food and beverage choices. You can build a healthy eating pattern by putting together foods from all food groups in different ways to match your personal preferences, economic situation and racial and ethnic backgrounds. The Dietary Guidelines framework purposefully provides recommendations by food groups and not specific foods or beverages to allow for flexibility. Each food group includes a broad range of nutrient-dense food options. Figure 3.11 shows how a carefully selected nutrient-dense meal can cover many, if not all, of the food groups. Food amounts can be adjusted to meet your calorie limits and preferences. Figure 3.12 shows how food selections consistent with a vegetarian, Mediterranean, and American style eating patterns can follow the principles promoted in the Dietary Guidelines.



Figure 3.11: Example of how a meal can provide nutrients from each of the food groups.



Figure 3.12: Healthy food combinations consistent with different eating patterns. Photos by Tania Melnyczuk, Chris Ralston, and Max Griss on Unsplash.

3. Focus on Meeting Food Group Needs with Nutrient-Dense Foods and Beverages and Stay within Calorie Limits

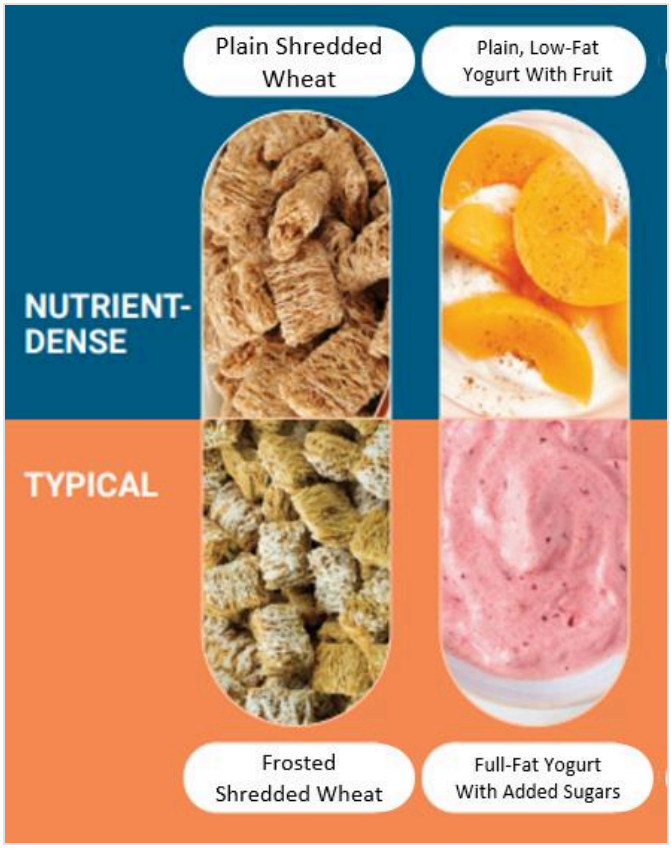


Figure 3.13: Making Nutrient-Dense Choices: One Food or Beverage at a Time

Incorporating all food groups, including different foods from each food group, will help ensure variety and maximize your diet's nutrient quality. Selecting foods that are high in **Nutrient density** (foods high in nutrients per calorie), helps you reach your nutrient recommendations within a day without going over your calorie level. The amount you consume is important as well. Serving sizes have increased in the last few decades and it has become easier to overeat. All foods can be enjoyed, if the amounts are appropriate. Figure 3.13 gives examples of nutrient-dense choices.

Small changes to meals can make a big difference in a person's overall nutrient and caloric intake. The nutrient-density of most food items or meals can be influenced by how it is prepared at home or by the manufacturer. For example, sugar and fats added to foods at home or during the manufacturing process will lower the nutrient-density.

4. Limit Food and Beverages Higher in Added Sugars, Saturated Fat, and Sodium. Limit Alcoholic Beverages.

The Dietary Guidelines recommends that 85% of calories needed per day should be met by with nutrient dense foods. The other 15% of calories are available for other uses, such as consumption of added sugars and saturated fats. American consumption of **empty calories**, or foods that contain a lot of calories and not very many nutrients, mostly in the form of saturated fats and added sugar, has been estimated to be about three times what they should be. It is difficult to meet your nutrient needs within a healthy caloric level when consumption of calories from added sugars and saturated fats is high. It is

recommended that Americans reduce their intake of foods and beverages high in these components to be consistent with the following guidelines:

- Consume less than 10% of total calories per day from added sugars
- Consume less than 10% of total calories per day from saturated fats
- Consume less than 2300 mg of sodium
- If alcohol is consumed, drink in moderation. Moderate drinking is defined as up to two drinks per day for men and up to one drink per day for women.

Added Sugar

The intake of added sugar in America is estimated to be about 13% of total calories, above the less than 10% recommendation. The major sources of added sugar in U.S diet are sugar sweetened beverages, desserts, and sweet snacks, sweetened coffee and tea and candy. More than half of American's added sugar intake comes from these food categories (see figure 3.14).5

These food categories contribute to total caloric intake but very little nutrient intake. Recommendations for lowering added sugar intake include reducing portions, consuming these items less often and selecting options low in added sugars.

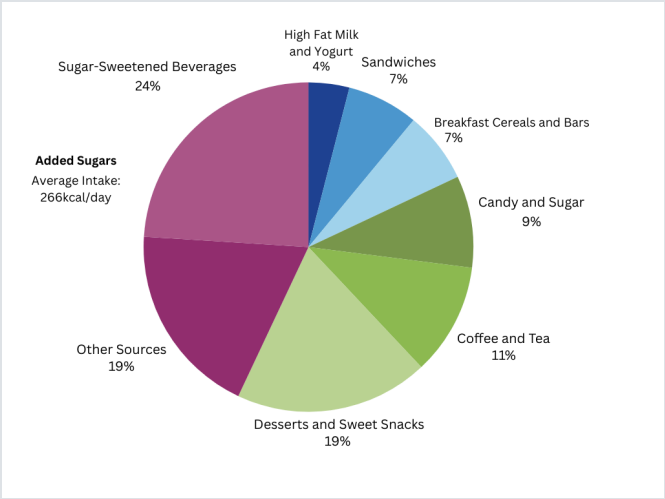


Figure 3.14: Top Sources and Average Intakes of Added Sugars: U.S. Population Ages 1 and Older. Created by Ap.

Saturated fat

The intake of saturated fat in America is estimated to be 11% of total calories, this is above the less than 10% recommendation.[10]

Only 23% of individuals meet the recommendation of less than 10% of calories from saturated fat. The main sources of saturated fat in the U.S. diet include sandwiches (eg hamburgers, tacos, and burritos), desserts and sweet snacks, and grain based foods with high fat sauces such as pastas with alfredo sauces (see figure 3.15). High levels of saturated fat occurs naturally in some foods (e.g. high fat meat). Saturated fat may be added to other foods during preparation such as putting butter on toast.

Strategies for decreasing intake of saturated fats include reducing portion size and eating frequency of foods high in saturated fat. Examples of ways to decrease saturate fat include preparing meals with leaner meats and low fat cheeses, and replacing high saturated fat items with healthy oils, nuts, seeds and avocados. Cooking with unsaturated oils like olive, canola or peanut oil in place of butter or shortening would also be helpful.

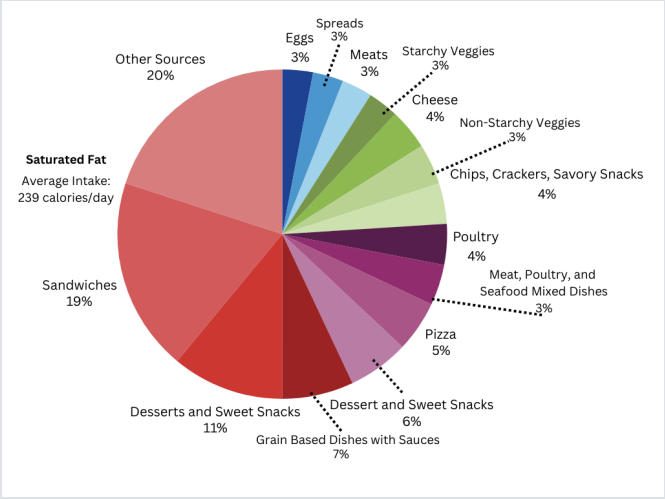


Figure 3.15: Top Sources and Average Intakes of Saturated Fat: U.S. Population Ages 1 and Older. Created by Ap.

Sodium

Sodium is an essential nutrient, but when consumed in excess it is thought to increase the risk for cardiovascular disease and high blood pressure. In America the average sodium intake of those ages 1 year and older is 3,393 milligrams per day.[10] The Dietary Guidelines recommend no more than 2300 mg of sodium per day. Most sodium intake comes from pre-prepared and processed foods, while very little of the intake comes from preparing foods at home or adding salt to your food at the table.

Suggestions to help reduce intake of sodium include eating less pre-prepared and processed foods which tend to be higher in sodium. Reading food labels for sodium content, and looking for “Reduced sodium”, “low -salt” or “No salt added” products. Choosing unsalted canned vegetables, and preparing food at home more often can help decrease sodium intake. Learning to flavor foods with herbs and spices instead of salt can help reduce sodium intake while maintaining flavor.

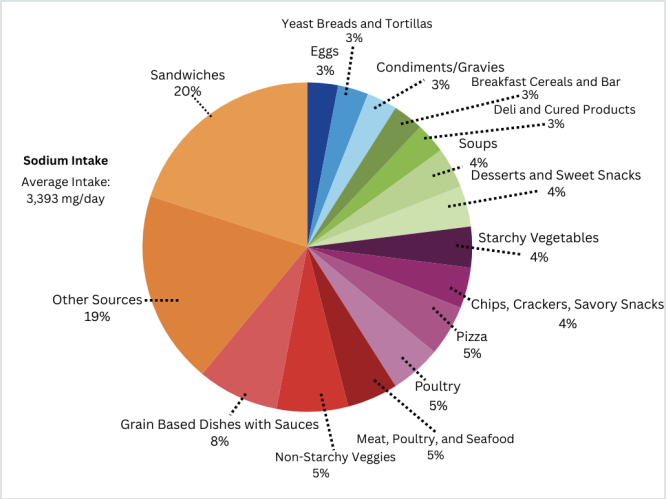


Figure 3.16: Top Sources and Average Intakes of Sodium: U.S. Population Ages 1 and Older. Created by Ap.

Alcohol

Dietary Guidelines recommends that individuals who do not drink alcohol should not start drinking for any reason. If a person does choose to drink, intake should be moderate, defined as up to two drinks per day for men and up to one drink per day for

women, and only by adults of legal drinking age. Calories provided by alcohol need to be accounted for in order to meet nutrient needs and stay within healthy calorie limits.

Summary

Dietary changes that decrease added sugar, saturated fat and sodium will decrease risk of chronic disease. Dietary changes that increase food groups, such as vegetables, fruits, low-fat dairy and whole grains will reduce risk of chronic disease by providing nutrients Americans are generally low in such as fiber, potassium and calcium.

Key Takeaways

- *The Dietary Guidelines for Americans are published every five years and are the foundation for public health programs and policies*
- *The guidelines focus on four key areas: healthy eating at every life stage, customizing your diet, choosing nutrient-dense foods, and limiting unhealthy components.*
- *On average, Americans consume more added sugar, saturated fat, and sodium than recommended.*
- *To improve health, the guidelines recommend limiting added sugars and saturated fats to under 10% of daily calories and sodium to under 2,300 mg per day.*
- *Most of these unhealthy components come from processed and prepared foods.*

References (see below)

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- 10. https://www.dietaryguidelines.gov/sites/default/files/2020-12/Dietary_Guidelines_for_Americans_2020-2025.pdf
- 12. United States Department of Agriculture. ChooseMyPlate.gov. ChooseMyPlate.gov website. https://www.choosemyplate.gov/. Updated March 20, 2017.

3.5

Using Choose MyPlate to Evaluate Food Intake

3.5 Using Choose MyPlate to Evaluate Food Intake

In conjunction with the release of the Dietary Guidelines, a graphic symbol has traditionally been used to represent healthy eating patterns. In 1992, the Food Guide Pyramid was introduced and later updated in 2005. For many years, it served as the main visual guide for the Dietary Guidelines for Americans. However, some people found it difficult to understand. In 2011, the pyramid was replaced with MyPlate, which is a simpler, plate-based design to help Americans build balanced meals more easily.

Key Nutrients in the Food Groups

The five food groups in the MyPlate guide are fruits, vegetables, grains, protein foods, and dairy. Using food groups helps make dietary recommendations easier to follow by focusing on foods rather than individual nutrients. Each group includes a variety of foods that provide similar key nutrients (see Figure 3.17).

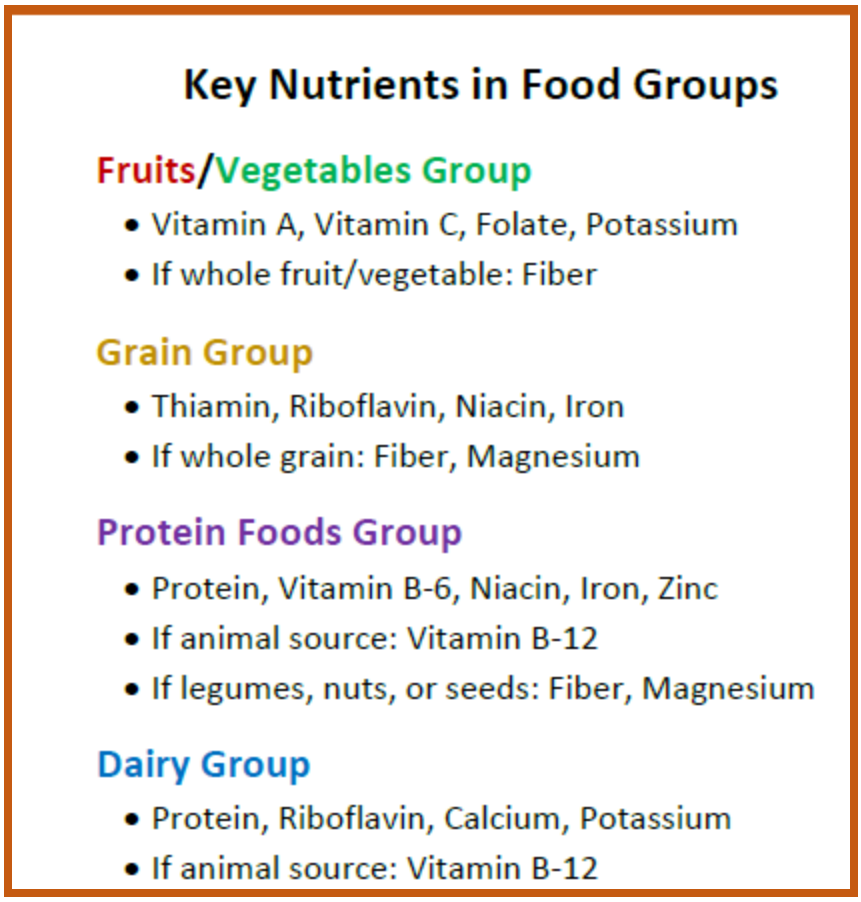


Figure 3.17: Key Nutrients in MyPlate Food Groups

Key nutrients in the fruits and vegetables food groups include vitamin A, vitamin C, folate (a B vitamin), potassium, and fiber. Although fruit and vegetable juices provide many of these nutrients, they are lower in fiber, so emphasis is placed on eating whole fruits and vegetables.

Whole grains in the grains group provide thiamin, riboflavin, niacin, iron, magnesium, and fiber. However, several nutrients are lost when grains are refined. Through the enrichment process, thiamin, riboflavin, niacin, and iron are added back, along with folate. Fiber, magnesium, and other nutrients are not added back.

The protein foods group includes a wide range of animal and plant sources. Key nutrients in this group include protein, vitamin B6, niacin, iron, and zinc. Vitamin B12 is also an important nutrient in animal-based protein foods. Plant-based options like legumes, nuts, and seeds also provide fiber and magnesium.

The dairy group includes milk, yogurt, cheese, and fortified soy beverages (such as soy milk). Other plant-based milks, like rice milk and almond milk, are not included because they do not provide enough protein. Key nutrients in this group include protein, riboflavin, calcium, and potassium. Vitamin B12 is also present in dairy foods from animal sources.

How to Use the MyPlate Food Guide

The MyPlate graphic shows how much each food group should appear in our daily meals. Fruits and vegetables should fill half of the plate, grains about one-quarter, and protein the other quarter. Dairy is included as a regular part of daily choices. To use this tool effectively, it is helpful to understand the principles behind it.

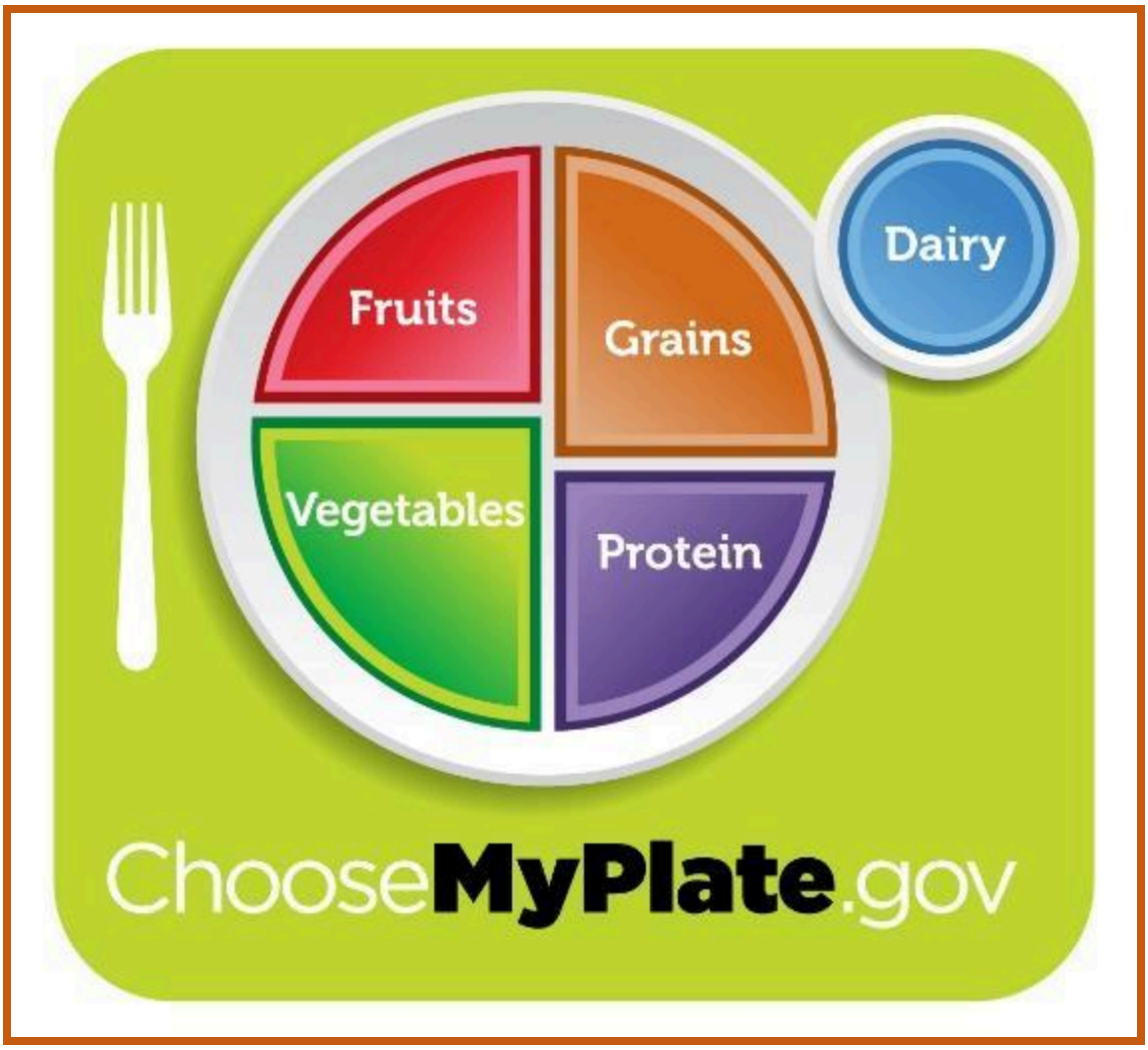


Figure 3.18: Choose MyPlate visual

When filling each section of the plate, it is important to remember the principles of variety, moderation, balance, and nutrient density. For example, choose a wide range of colorful fruits and vegetables, pick whole grains at least half the time, select lean proteins like chicken and fish more often, and include more plant-based proteins such as legumes, nuts, and seeds.

The recommended amount of food from each group depends on a person's calorie needs.

Food group amounts are given in cup or ounce equivalents. It is important to understand the term **equivalents**. For instance, on a 2,000-calorie diet, the recommendation is about 2 cup equivalents of fruit per day. However, this does not always mean 2 actual cups of fresh fruit. Dried fruit takes up less space, so only ½ cup of dried fruit counts as 1 cup equivalent. For example, ½ cup of raisins equals 1 cup equivalent of fruit.

A cup of raw or cooked vegetables, or vegetable juice, generally counts as one cup equivalent of vegetables. However, it takes 2 cups of raw leafy greens (like spinach) to equal one cup equivalent because leafy greens are less dense.

The grain group is measured in ounce equivalents and is generally straightforward. However, it is important to watch for added fats and sugars. For example, a two-ounce serving of a muffin and a two-ounce serving of sandwich bread both count

as grain servings but differ in calorie content because muffins often contain added fat and sugar. Calories from these additions are called empty calories.

Dairy group cup equivalents are based on calcium content, with one cup equivalent providing about 300 mg of calcium. For milk and yogurt, 1 cup equals 1 cup equivalent. With cheese, the calcium is more concentrated due to the removal of liquid during processing. As a result, 1 ounce of processed cheese or 1.5 ounces of hard cheese (like cheddar) equals 1 cup equivalent of dairy (see Figure 3.19).

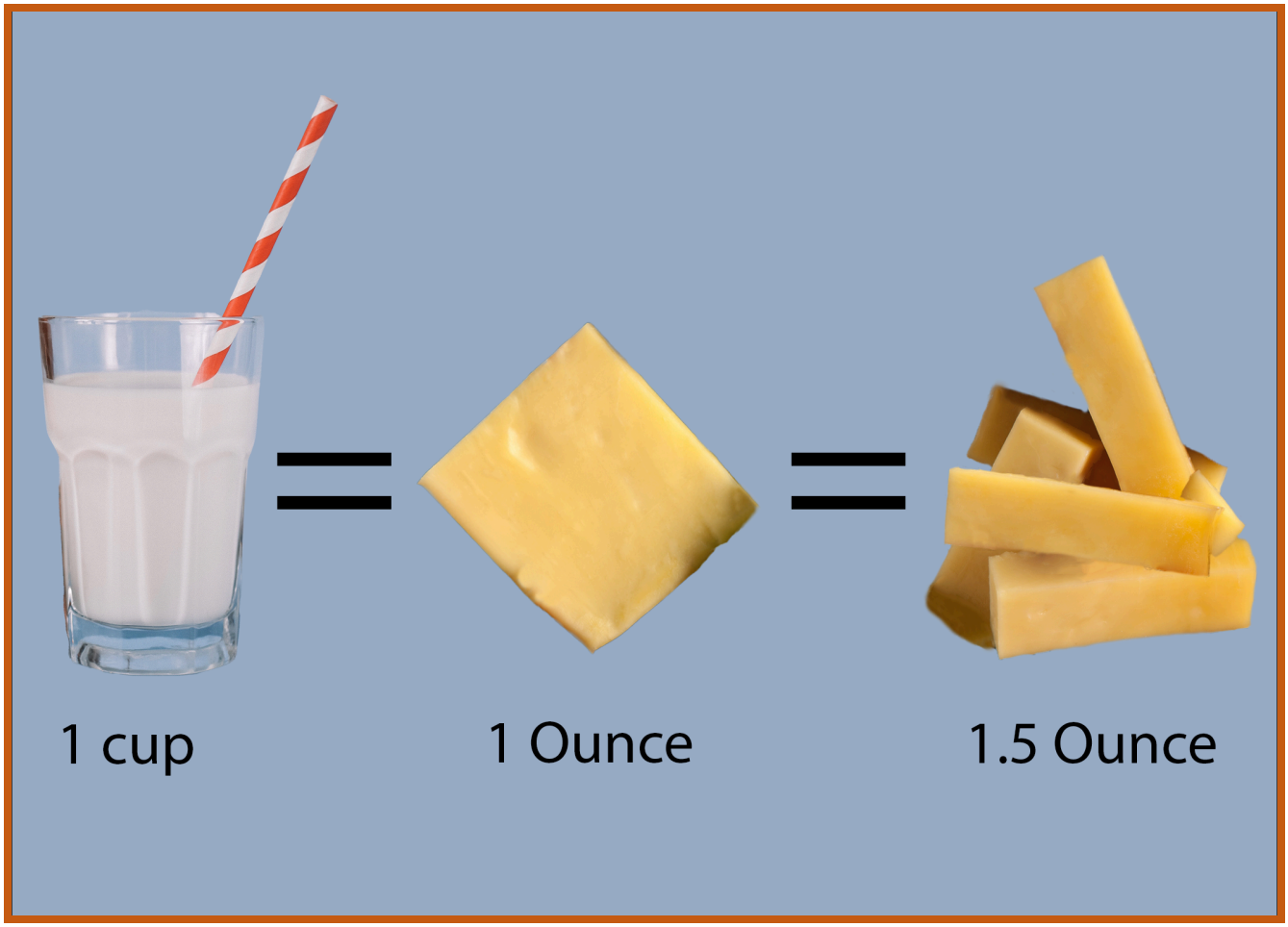


Figure 3.19: Cup equivalents from the Dairy Group is based on calcium content.

1 ounce = 28.3 grams. 1.5 ounces = 43.5 grams. Photos by Kate Mishchankova, Önder Örtel, and Önder Örtel on Unsplash.

When dealing with meat equivalents in the protein group, typically 1 ounce of meat equals 1- ounce equivalent in the Protein Foods. But the Protein Foods group is a diverse group, a variety of high protein non-meat foods need to be accounted for when scoring protein intake (such as nuts, seeds and legumes). Serving sizes for these products vary.

Key Takeaways

- *MyPlate is a simple guide that replaced the Food Guide Pyramid in 2011 to help Americans build balanced meals.*
- *The five food groups are fruits, vegetables, grains, protein foods, and dairy, each providing different key nutrients.*
- *The MyPlate graphic suggests filling half of the plate with fruits and vegetables, one-quarter with grains, and one-quarter with protein, with dairy as a separate component.*

- *The guide emphasizes principles like variety, moderation, balance, and nutrient density, and uses the concept of "equivalents" to account for different food forms (e.g., fresh vs. dried fruit).*

References (see below)

- 1. The Holy Bible, KJV. Salt Lake City, UT: Intellectual Reserve, Inc; 1979.
- 2. Doctrine and Covenants. Salt Lake City, UT: Intellectual Reserve, Inc; 1981:176.
- 3. Wolf G. A history of vitamin A and retinoids. FAESB J. 1996; 10(9): 1102-1107.
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- 5. Carpenter KJ. A short history of Nutritional Science: Part 1. J Nutr. 2003; 133(3): 638-645.
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3.6

Translating Principles to Practice

3.6 Translating Principles to Practice

Identifying Cups and Ounces

In order to translate principle into practice an understanding of what a cup or ounce of the various foods looks like can be helpful. Using familiar objects can be a good way to visualize the different serving sizes (see Figure 3.20).

Not The Right image

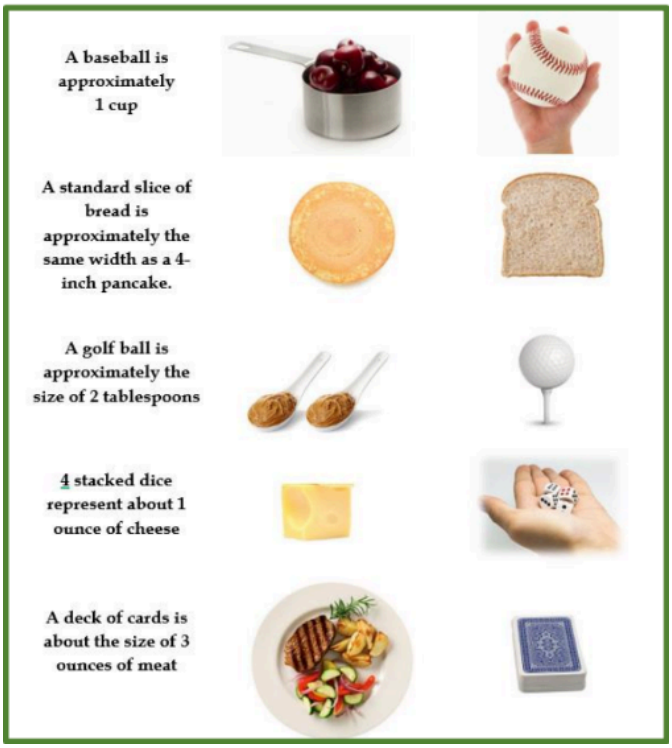


Figure 3.20: Measuring amounts of food using common objects

1 ounce of cheese = 28 grams, 3 ounces of meat = 85 grams. Measuring Cup Photo by Jonatan Svensson Glad under CC BY-SA 4.0 license with editing. Baseball Photo by Chris Briggs on Unsplash. Bread Photo by Seriously Low Carb on Unsplash. Pancake Photo by nichiiro on Unsplash. Tablespoon Photo by Dean Ricciardi on Unsplash. Golf Ball Photo by Sugar Golf on Unsplash. Cheese Photo by Önder Örtel on Unplash. Dice Photo by Terry Vlisidis on Unsplash. Steak Photo by Food Photographer on Unsplash. Card Photo by Aditya Chinchure on Unsplash.

Finding the Right MyPlate Plan for You

Because body size, gender, age, and activity level differ among people, calorie needs and the recommended cup or ounce equivalents vary individually. By entering your information on the MyPlate website, you can receive personalized recommendations that match your specific profile.

To show how serving amounts translate into food, we use a general example based on a 2,000-calorie diet. Figure 3.20 illustrates what this amount of food looks like.

When choosing foods, it is important to remember the principles of variety, balance, moderation, and nutrient density. Enjoying foods high in added fats and sugars occasionally is okay and can fit into the MyPlate plan, but it is important to make choices that support these principles most of the time.

Food Guides from Around the World

According to the Food and Agriculture Organization of the United Nations (FAO) worldwide there are more than 100 countries that have also developed a food guide for healthy eating. Most countries in Asia and the Pacific, Europe, North America and Latin American have national dietary guidelines. Several countries in Africa and the Middle East also have guidelines developed.[13] The selected style of the food guides varies. Many countries have a circular visual similar to MyPlate used in the United States. A pyramid representation is also fairly common. Other countries have selected visuals that are creative and often unique to their culture (see Table 1 for examples). Despite a variety of designs, foods are typically grouped in a manner similar to MyPlate.

Country	Food guide shape
China	Pagoda (a many tiered tower)
Japan and Venezuela	Spinning top
Qatar	Clam shell
Saudi Arabia	Palm Tree
Grenada	Nutmeg
Antigua and Barbuda	Pineapple
Bahamas	Goat skin drum

Country	Food guide shape
Dominica	A basket carried by an imperial parrot
Guatemala and Honduras	Family Pot

Table 1: Examples of unique food guides from around the world[13]

Some countries have several image options. For example, Germany has developed a nutrition circle as well as three dimensional Food Pyramid. The Philippines has also developed a plate and pyramid representation that can be viewed based on age or for pregnancy or lactation. In Figures 3.21-3.24 are some examples of food guides from other countries.[14-17]



Figure 3.21: Nutrition Circle from the German Nutrition Society. The German Nutrition Society has also developed a 3 dimensional Food pyramid. The nutrition circle is printed on the bottom surface of the pyramid. (Printed with permission of the German Nutrition Society- Usage is typically restricted outside Germans speaking area because it is based on the D-A-CH Reference Values for Nutrient Intake).[14]

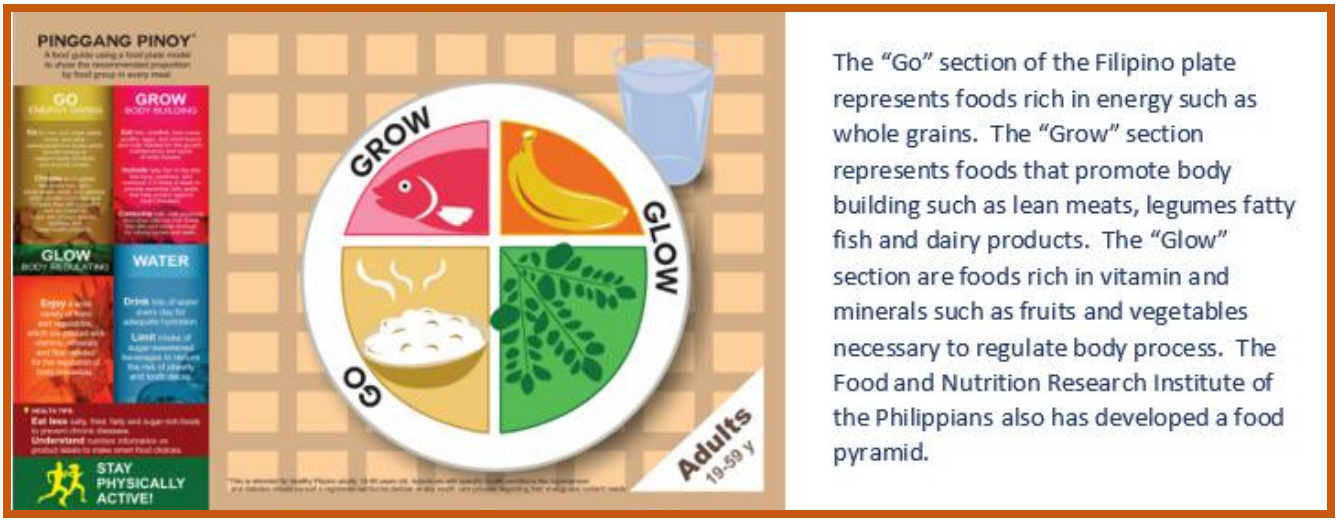


Figure 3.22: Filipino plate. The Food and Nutrition Research Institute of the Philippines has produced adaptations of the plate for different age groups and for pregnant and lactating mothers. (© Republic of the Philippines, Food and Nutrition Research Institute-DOST)[15]

Having dietary guidelines and food guides developed for each country is an opportunity to target the diet modifications and challenges most needed by the people that live in that country.

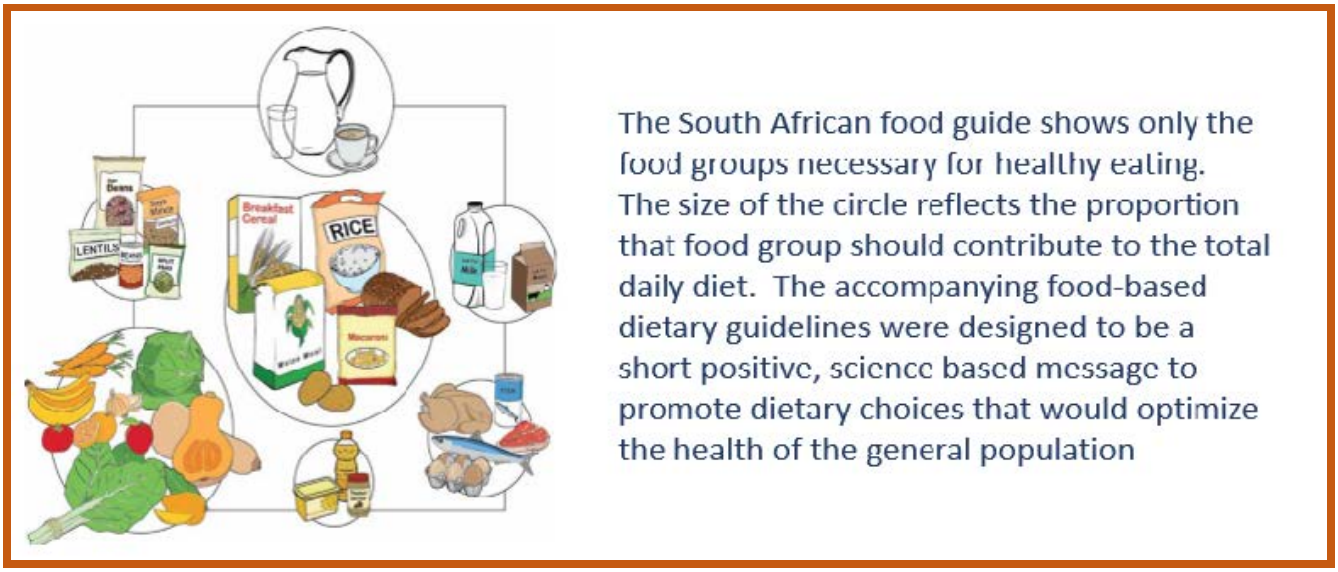


Figure 3.23: South African Food guide. (Printed with permission from the Department of Health: Republic of South Africa).[16]

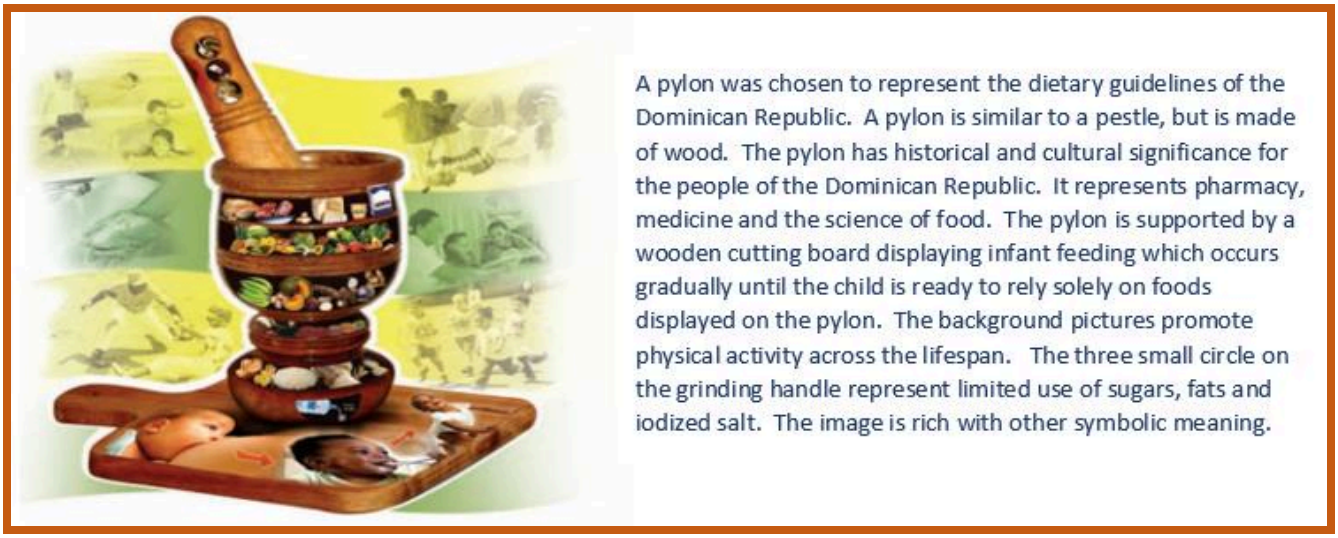


Figure 3.24: The pylon of food and nutrition from the Dominican Republic. (Guías Alimentarias Basadas. en Alimentos de la República Dominicana. © Despacho de la Primera Dama. SESPAS, Nutrición).[17]

Despite a wide variety of different graphical representations, generally a diet pattern that is varied, moderate and balanced is encouraged. Nutrient dense foods selected from all the food groups daily is consistent across cultures. Carbohydrate rich foods such as rice, beans and bread products are a common component of global diets. While these are healthy food choices, it is important to recognized they are only 1 part of an adequate diet. To ensure optimal nutrition, all foods groups need to be regularly included in a meal plan. Examples of a day's menu that represents a healthy eating pattern from a few different countries is displayed in Table 2. Some of the foods may not be familiar to you, pictures are included of a few of the dishes to illustrate their contents.

	USA	Africa (Kenya)	Philippines	Brazil
Breakfast	Oatmeal with blueberries Whole grain toast with peanut butter Yogurt *Grain, Fruit, Protein, Dairy*	Fermented millet porridge Scrambled eggs Pawpaw slice Milk *Grain, Protein, Fruit, Dairy*	Fried bangus (Fish) Camote tops salad (Sweet potato leaves) with tomatoes Rice Banana *Protein, Veggie, Grain, Fruit*	Milk Couscous Eggs Banana *Dairy, Grain, Protein, Fruit*
Lunch	Mixed green salad Chicken sandwich on whole grain bread Banana *Veggie, Grain, Protein, Fruit*	Mokimo (mashed potatoes and green vegetables), Steamed cabbage Meat ball in sauce Slice of pineapple *Veggie, Protein, Fruit*	Chicken tinola with green papaya and mulunggay Mango Rice *Protein, Veggie, Fruit, Grain*	Rice Beans Beetrot Baked Chicken Leg Cornmeal with Cheese *Grain, Veggie, Protein, Dairy*
Dinner	Oven roasted Tilapia Mixed vegetables with pasta Orange Glass of milk Protein, Grain, Veggie, Fruit, D	Boiled sweet potato Beef Stew Steamed amaranth Sliced paw paw *Veggie, Protein, Grain, Fruit*	Fried Gulunggong (fish) Pinakbet (vegetable-dish - pakbet) Rice Milk Watermelon *Grain, Veggie, Grain, Protein, Fruit*	Rice Beans Sautéed Zucchini Boiled egg Apple *Grain, Veggie, Protein, Fruit*

Table 2: Health eating patterns based of the dietary guidelines of select countries.[18,19,20]



Figure 3.25: Foods included in healthy meal plans from selected countries. Photo Fried Bangus by Pelican under the CC BY-SA 2.0 license with edits. Pinakbet Photo by Thepacificconoisseur at en.wikipedia under CC BY-SA 3.0 license with edits. Pawpaw Fruit Photo by Cbarlow under CC BY-SA 4.0 license with edits. Millet Photo by T.K. Naliaka under CC BY-SA 4.0 license with edits. Tilapia Photo by Fernanda Rodríguez under CC BY-SA 4.0 license with edits. Photo Chicken Tinola by Joy D. Ganaden under CC BY-SA 4.0 license with edits.

With an increasing global availability of cheap, ultra-processed foods, the continued development and refinement of the dietary guidelines for each country is important to help guide the dietary choices of people living in those areas. The nutritional challenges of a country are best address through guidelines that are developed locally.

Key Takeaways

- *You can use familiar objects to help visualize appropriate serving sizes.*
- *MyPlate recommendations are individualized based on factors like a person's age, gender, body size, and activity level.*
- *Over 100 countries have their own unique food guides, with visuals that often reflect their culture.*
- *Despite different designs, most global food guides share the same core principles of variety, balance, moderation, and nutrient density.*
- *Developing country-specific dietary guidelines is important for addressing the local nutritional challenges and dietary patterns of that population.*

References (see below)

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4

Chapter 4: Vitamins

4.1. Introduction to Vitamins

4.2. Characteristics of Vitamins

4.3. Water-Soluble Vitamins

4.4. Fat-Soluble Vitamins

4.1

Introduction to Vitamins

10.1 Introduction to Vitamins

The identification and importance of carbohydrate, protein, lipids, and minerals in the dietary intake were established during the late 17th and early 18th century. However, the discovery of vitamins did not occur until the late 18th and early 19th century. During the end of the 1800's, scientists conducted deprivation studies where mixtures containing only carbohydrate, protein, lipids, and minerals were fed to animals. The animals did not survive on these diets which indicated the diets were lacking other substances that were essential to health. Referring to these studies, Gerrit Grijns in 1901 stated, "There occur in natural foods, substances, which cannot be absent without serious injury."[1]

In 1912, while Casimir Funk studied the disease beriberi and an antiberiberi factor, he found the factor contained an amine group. He hypothesized other conditions such as scurvy, rickets, and pellagra was caused by deficiencies of similar compounds containing amine groups. He thought these substances contained vital amines and coined the name "vitamines." After it was discovered not all the substances contained an amine group, the "e" was dropped and the term became vitamin.[2]

Key Takeaways

- *The importance of carbohydrates, proteins, lipids, and minerals was established long before the discovery of vitamins.*
- *Early deprivation studies showed that diets containing only the known macronutrients and minerals were insufficient to sustain life, indicating the existence of other vital substances.*
- *In 1912, Casimir Funk coined the term "vitamine" based on his belief that these essential factors were "vital amines."*
- *The "e" was later dropped from the name to create the term "vitamin" when it was discovered that not all of these substances contained an amine group.*

References (see more)

- 1. Carpenter KJ. A short history of nutritional science: Part 2 (1885-1912). J Nutr, 2003; 133:975-984.

- 2. Carpenter KJ. A short history of nutritional science: Part 3 (1912-1944). J Nutr. 2003; 133:3023-3032.

4.2

Characteristics of Vitamins

10.2 Characteristics of Vitamins

Vitamins are organic compounds that are needed by the body in very small amounts. Since the body cannot make them or makes them in insufficient amounts, vitamins are essential to consume. 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.

> Organic compounds – a chemistry term for compounds containing carbon attached to other elements such as hydrogen, oxygen, and nitrogen. Carbohydrate, protein, lipids, and vitamins are organic compounds. This differs from organic food which refers to how the food was grown or raised.

Vitamins are classified by their biological functions, and some of the vitamins have more than one active chemical structure capable of meeting a nutritional requirement. The groups of chemically related compounds are referred to as vitamers.[3,4] For example, vitamers for vitamin B_6 include pyridoxine, pyridoxal, and pyridoxamine.

Water-Soluble and Fat-Soluble Vitamins

Vitamins can be categorized as either fat-soluble or water-soluble (see Table 1). Water-soluble vitamins readily disperse in a water solution, whereas the fat-soluble vitamins will not. These differences in solubility affect how they are absorbed, transported, stored, and excreted by the body. For example, water-soluble vitamins readily travel in the blood which is water-based, but fat-soluble vitamins need a transporter.

Water-soluble Vitamins	Fat-soluble Vitamins
B-Vitamins	**Vitamin A** (Retinol)
Thiamin	**Vitamin D** (Cholecalciterol)
Riboflavin	**Vitamin E** (Alpha-tocopherol)

Water-soluble Vitamins	Fat-soluble Vitamins
Niacin	**Vitamin K**
Biotin	
Pantothenic acid	
Vitamin B6 (Pyridoxine)	
Folate	
Vitamin B12 (Cobalamin)	
Vitamin C (Ascorbic acid)	

Table 10.1: Water-soluble and fat-soluble vitamins (most common vitamer listed for select vitamins)

Stability of Vitamins

The structure of certain vitamins often degrade the longer it is stored, the higher the temperature, and the greater amount of exposure the food has to light and air. After the vitamin structure has broken down, it will no longer be able to function as a vitamin. Since vitamin C, a water-soluble vitamin, is sensitive to heat, light, and oxygen, it is often used as an indicator of nutrient degradation (see Figure 1).[5]

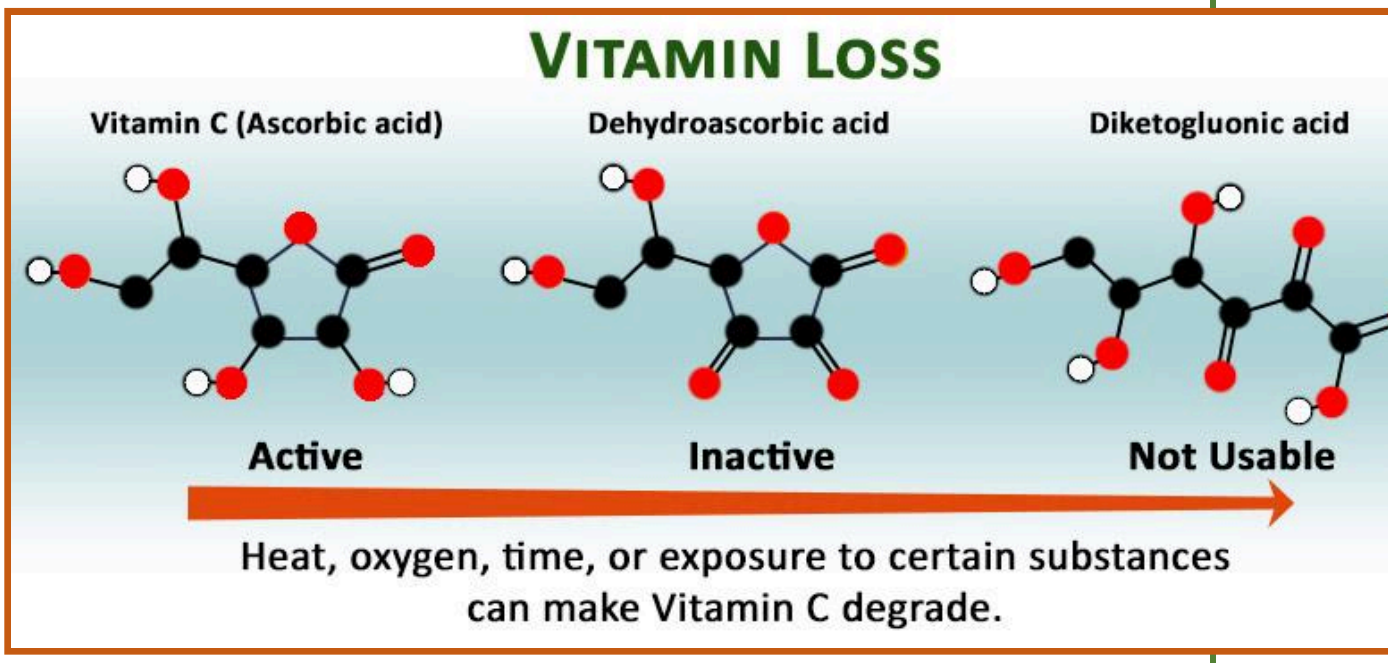


Figure 10.1: Vitamin C degradation

The highest amounts of vitamins in fruits and vegetables will be immediately post-harvest when the plant has reached peak maturity. Nutrient retention for fresh fruits and vegetables can be maximized if they are handled carefully and stored at cool temperatures. Surprisingly, commercially frozen vegetables have either the same or higher amounts of vitamin C as those found "market fresh" because the frozen vegetables are usually harvested, blanched, and quickfrozen within a day and "market fresh" vegetables typically spend 3 to 7 days in retail distribution and storage before they are bought.[6]

Recommendations to minimize vitamin loss in foods include:

- Cut vegetables and fruits close to cooking and serving times.
- Steam, microwave, or use small quantities of water to minimize the amount of water-soluble vitamins leaching out of the food.
- Do not overcook vegetables.
- Do not add baking soda when cooking vegetables or legumes because baking soda makes the water alkaline which can destroy certain vitamins (such as thiamin).
- Store canned goods at cool temperatures and use canned goods within a year.

Provitamins

A provitamin is a substance found in food that can be converted into a vitamin within the body. An example of a provitamin is beta-carotene, a pigment found in many fruits and vegetables, which can be converted to vitamin A (see Figure 2).

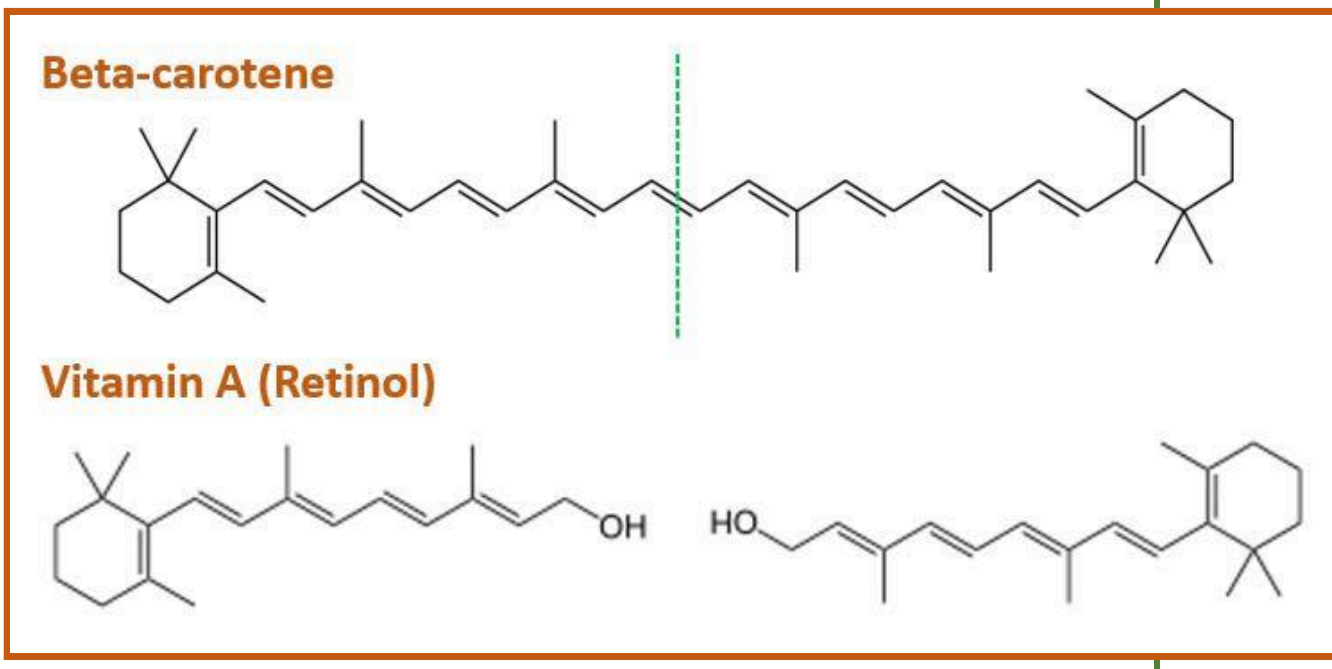


Figure 10.2: Beta-carotene can be converted by the body into vitamin A (retinols)

Antioxidant

Oxidation by free radicals in the body can cause cellular damage. A free radical is a molecule with an unpaired electron. The free radical's unbalanced "electrical field" makes the free radical highly unstable and it needs another electron to stabilize it. Stealing an electron (oxidizing) from another molecule stabilizes the free radical but damages the other molecule. An antioxidant can donate an electron to the free radical and remain stable, thus protecting the other molecules from oxidative damage (see Figure 3). Vitamin C, vitamin E, and beta-carotene (a provitamin for vitamin A) are antioxidants.

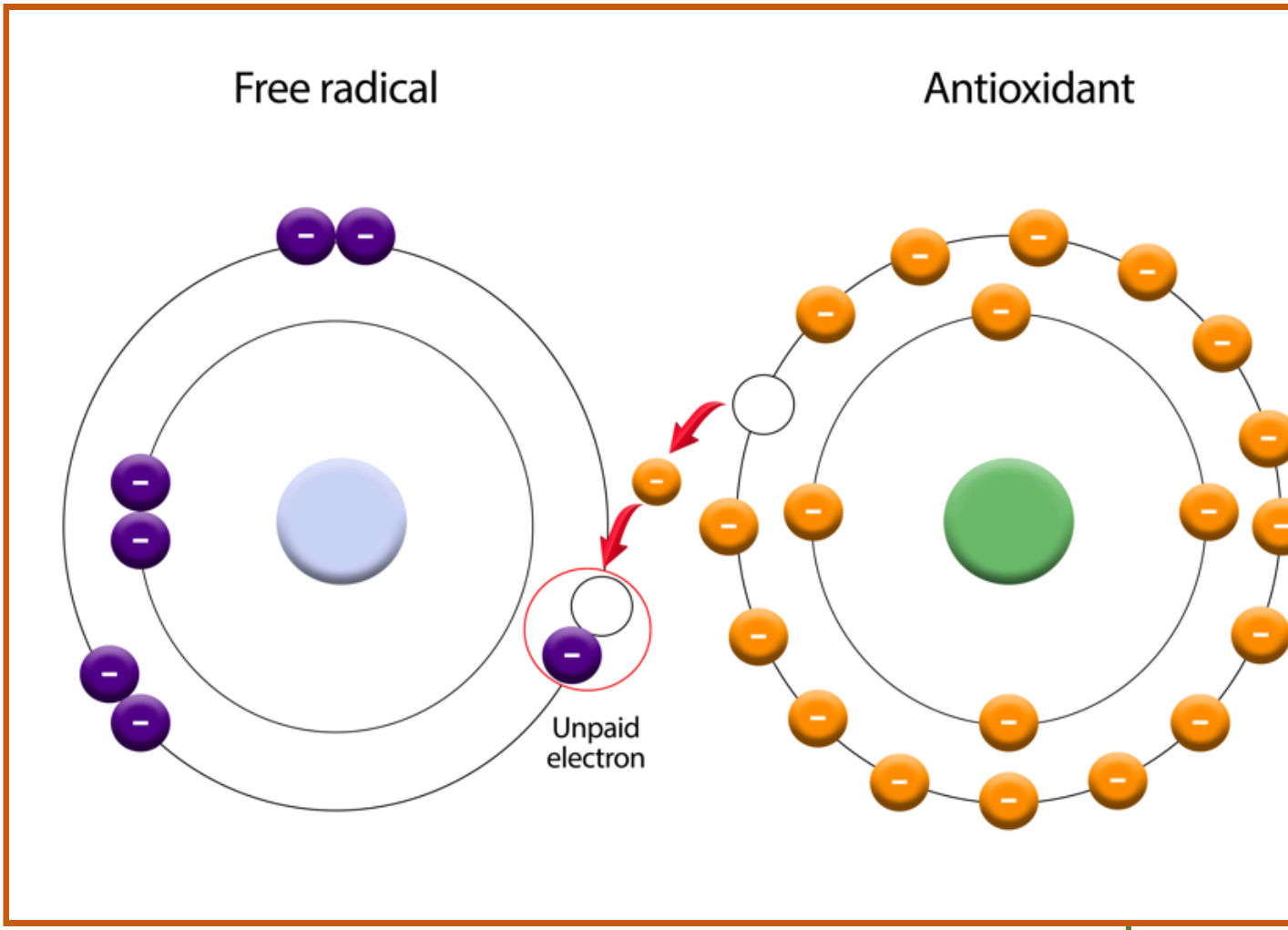


Figure 10.3: Antioxidants can donate an electron to neutralize free radicals. Created by AL.

Coenzymes

A coenzyme is an organic non-protein compound that activates an enzyme so it can work (see Figure 4). The water-soluble vitamins and vitamin K can function as a coenzyme.

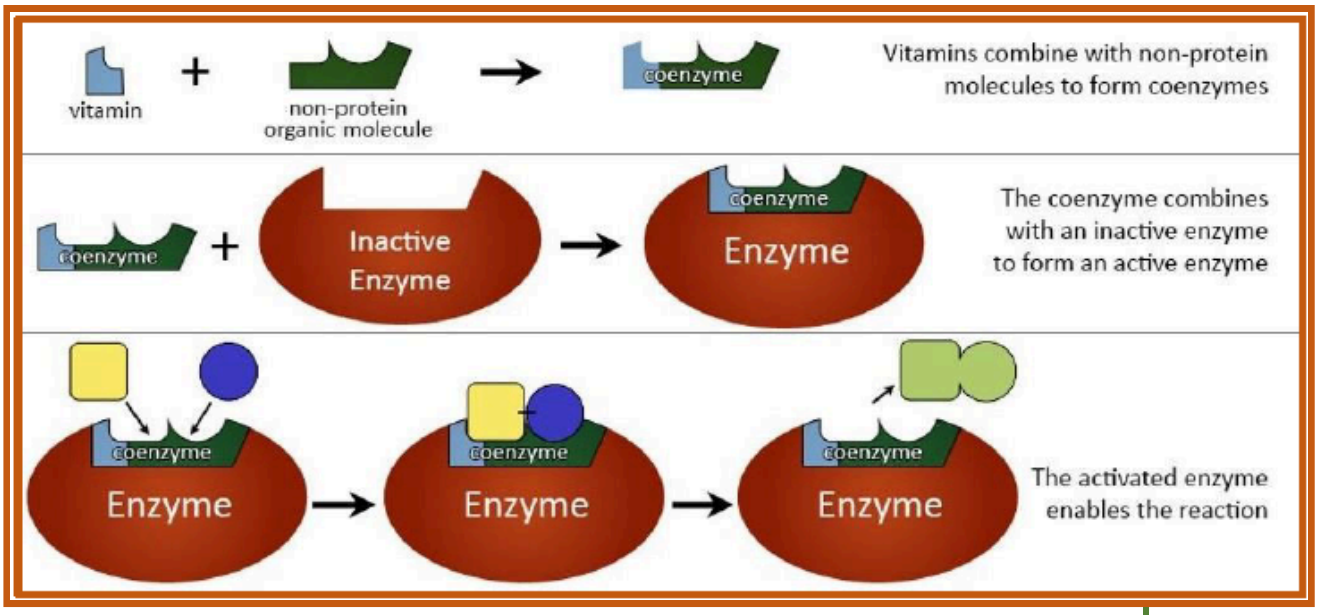


Figure 10.4: Coenzymes

Bioavailability

Bioavailability refers to the body's ability to absorb the nutrient into the digestive tract and utilize it. A number of factors can influence the bioavailability of vitamins. For example, fatsoluble vitamins have a higher bioavailability when there is at least a small amount of dietary fat consumed at the same time. A fat-free dietary intake lowers the bioavailability.[7,8,9,10] Another factor that may affect a vitamin's bioavailability is the amount that is consumed. For example, when 30 to 180 milligrams of vitamin C is consumed in a day, approximately 70 to 90% is absorbed. However, when doses of 1 gram (1,000 milligrams) or higher are consumed, absorption drops to less than 50%.[11]

Key Takeaways

- *Vitamins are organic compounds that are essential to consume in very small amounts, as the body cannot produce them in sufficient quantities.*
- *Vitamins are classified as either water-soluble (B-vitamins and C) or fat-soluble (A, D, E, and K), which affects how they are absorbed and used by the body.*
- *Vitamins in food can degrade when exposed to heat, light, and air. Cooking methods like steaming can help preserve their content.*
- *Vitamins can act as antioxidants to protect cells from damage or as coenzymes to help enzymes function properly.*
- *The bioavailability of vitamin (how well it is absorbed and used) can be influenced by factors such as the presence of fat in a meal and the amount of the vitamin consumed.*

References (see more)

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4.3

Water-Soluble Vitamins

10.3 Water-Soluble Vitamins

Thiamin

Thiamin, also known as vitamin B_1, has coenzyme and non-coenzyme functions in the body. Thiamin acts as a coenzyme in carbohydrate metabolism to help convert pyruvate to acetyl CoA. Thiamin also has a coenzyme role in the synthesis of components of RNA, DNA, and ATP. Thiamin has non-coenzyme roles in brain functions, muscle contraction, nerve tissue repair, and the immune system.[12]

Thiamin Sources

The RDA for thiamin increases as an infant grows, but once adulthood is reached, it remains constant at 1.2 milligrams per day for males and 1.1 milligrams per day for non-pregnant women (see Table 2).

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	0.2 mg*	0.2 mg*		
7-12 months	0.3 mg*	0.3 mg*		
1-3 years	0.5 mg	0.5 mg		
4-8 years	0.6 mg	0.6 mg		
9-13 years	0.9 mg	0.9 mg		
14-18 years	1.2 mg	1.0 mg	1.4 mg	1.4 mg

Age	Male	Female	Pregnancy	Lactation
19-50 years	1.2 mg	1.1 mg	1.4 mg	1.4 mg
51+ years	1.2 mg	1.1 mg		

* Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations.

Table 10.2: Thiamin DRI recommended intakes[13]

Thiamin Deficiency and Toxicity

Historically, the thiamin deficiency beriberi was prevalent in societies whose main dietary staple was polished white rice. During the harvesting of rice, the husk was taken off the rice, resulting in brown rice. Then the brown rice was polished to remove the bran layer which contained most of the thiamin. The resulting polished white rice was a poor dietary source of thiamin.

There are two types of beriberi: dry and wet. Symptoms of dry beriberi include a loss of muscle function or paralysis of the lower legs. Wet beriberi can cause an enlarged heart, edema in the lower legs, and shortness of breath.[14]

Today beriberi is rare in the United States because thiamin is enriched (added back) to processed grains. However, beriberi still occurs in refugee camps where the primary source of food is polished rice that is not fortified.[15]

Alcoholics are at risk for a thiamin deficiency known as Wernicke-Korsakoff Syndrome. Up to 80% of people with chronic alcoholism have a thiamin deficiency.[15]

Usually alcoholics have a low intake of thiamin due to alcohol displacing good food sources of thiamin. Also, alcohol decreases the absorption of thiamin and increases thiamin excretion. Symptoms of Wernicke-Korsakoff Syndrome include impaired muscle coordination, involuntary eye movements, memory loss, and confusion.[14]

There are no reports of adverse effects from excessive thiamin intake by food and supplements. Hence, a UL has not been established for thiamin.[16]

Riboflavin

Riboflavin, also known as vitamin B_2, is an essential component of coenzymes FAD and FMN. These coenzymes play major roles in energy (ATP) production, cellular function, and growth. The riboflavin coenzymes have several other roles including the synthesis of niacin from the provitamin tryptophan and the activation of vitamin B_6.

The “flavin” portion of riboflavin gives a bright yellow color to riboflavin, an attribute that helped lead to its discovery as a vitamin. When riboflavin is taken in excessive amounts, very little of it is stored in the body tissues. The majority of the excess riboflavin is excreted in the urine, giving the urine a bright yellow color.[17]

Riboflavin Sources

Riboflavin food sources include milk, cheese, meat, eggs, whole grains, and enriched grains (riboflavin is one of the five nutrients added back to the enriched grains). Riboflavin is relatively stable during cooking but can rapidly break down when exposed to light. Milk is often packaged in opaque containers to protect the riboflavin from the light.



Figure 10.5: BeriBeri. Image by Collectie Wereldmuseum (v/h Tropenmuseum), part of the National Museum of World Cultures under CC BY-SA 3.0 license.



Figure 10.6: Riboflavin in water (notice the bright yellow color) Image by PatríciaR under CC BY-SA 4.0 license, CC BY-SA 3.0 license, CC BY-SA 2.5 license, CC BY-SA 2.0 license, and CC BY-SA 1.0 license

Riboflavin Recommendations

Similar to thiamin, the RDA for riboflavin increases as an infant grows, but once adulthood is reached, it remains constant at 1.3 milligrams per day for males and 1.1 milligrams per day for non-pregnant women (see Table 3).

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	0.3 mg*	0.2 mg*		
6-12 months	0.4 mg*	0.3 mg*		
1-3 years	0.5 mg	0.5 mg		
4-8 years	0.6 mg	0.6 mg		
9-13 years	0.9 mg	0.9 mg		
14-18 years	1.3 mg	1.0 mg	1.4 mg	1.6 mg
19-50 years	1.3 mg	1.1 mg	1.4 mg	1.6 mg
51+ years	1.3 mg	1.1 mg		

* Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations.

Table 10.3: Riboflavin DRI recommended intakes[13]

Riboflavin Deficiency and Toxicity

Riboflavin deficiency, ariboflavinosis, is often accompanied by other dietary deficiencies (most notably protein) and can be common in people that suffer from alcoholism. The signs of ariboflavinosis include dry, scaly skin, mouth inflammation and



Figure 10.7:Milk packaged in an opaque container. Created by AL.

angular cheilitis, magenta tongue, and sore throat. 17



Figure 10.8: Angular cheilitis. Image by Matthew Ferguson 57 under CC BY-SA 3.0 license.

A UL has not been established for riboflavin because no adverse effects from riboflavin food and supplement intakes have been reported.[17]The excess riboflavin is rapidly excreted in the urine, giving the urine a bright yellow color.

Niacin

Niacin, also known as vitamin B_3, has two vitamers: niacinamide and nicotinic acid (not related to nicotine). Niacin is a component of the coenzymes NADH and NADPH, which are involved in the catabolism and anabolism of carbohydrates, lipids, and proteins. The NADH coenzyme is a carrier of the high energy electrons produced in glycolysis and the citric acid cycle and transfers them to the electron-transport chain to make ATP. NADPH is required for the anabolic pathways of fatty acid and cholesterol synthesis.[18]

Niacin Sources

Excellent food sources of niacin include chicken, tuna, turkey, beef, and fish. Other good sources include peanuts, whole grains, and enriched grains (niacin is one of the five nutrients added back to the enriched grains).

Although corn contains niacin, the niacin is bound by substances which drastically lower its bioavailability. If corn is treated in an alkaline solution, such as lime water, the bound niacin is released and its bioavailability is increased.

In humans, niacin can be synthesized from the essential amino acid tryptophan (see Figure 5). Tryptophan is the provitamin for niacin. The synthesis process requires riboflavin, vitamin B_6, and iron. It usually requires 60 milligrams of tryptophan to make 1 milligram of niacin. Since both niacin and tryptophan are considered sources of niacin, a unit of measure called niacin equivalents (NEs) was developed to account for the potential niacin from tryptophan. One niacin equivalent is equal to one milligram of niacin or 60 mg of tryptophan.[18]

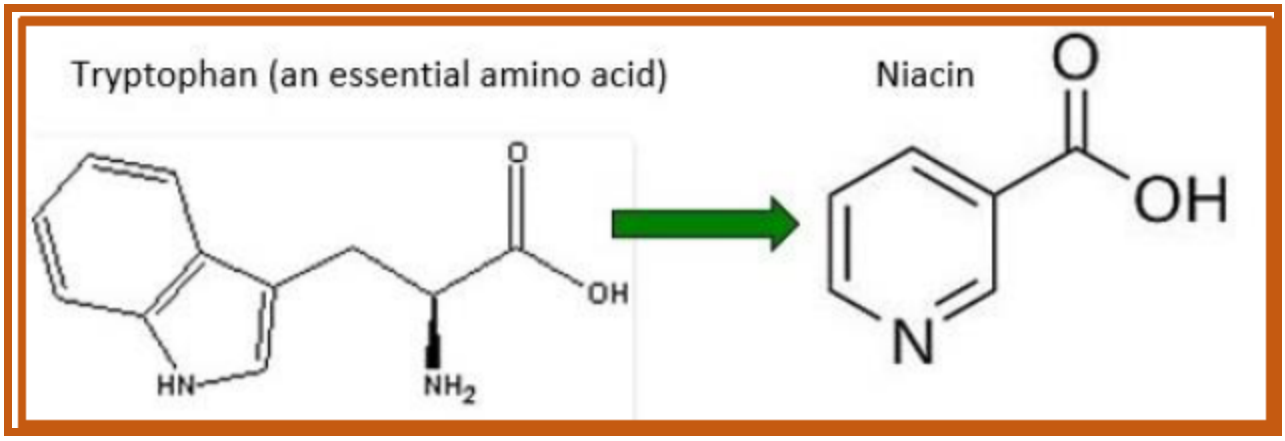


Figure 10.9: Conversion of tryptophan (an essential amino acid) to niacin

Niacin Recommendations

The recommendations for niacin are given in niacin equivalents (NE) to account for the niacin found in food as well as the niacin that can be synthesized from tryptophan.

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	2 mg NE*	2 mg NE*		
7-12 months	4 mg NE*	4 mg NE*		
1-3 years	6 mg NE	6 mg NE		
4-8 years	8 mg NE	8 mg NE		
9-13 years	12 mg NE	12 mg NE		
14-18 years	16 mg NE	14 mg	18 mg NE	17 mg NE
19-50	16 mg NE	14 mg NE	18 mg NE	17 mg NE
51+ years	16 mg NE	14 mg NE		

* Indicated Adequate Intake recommendation. Bolded items indicate RDA recommendations. NE = niacin equivalent.

Table 10.4: Niacin DRI recommended intakes[13]

Niacin Deficiency and Toxicity



Figure 10.10: A person suffering from pellagra. Image by Wellcome Collection gallery (2018-03-23) under CC BY 4.0 license.

Pellagra is a disease resulting from severe niacin deficiency. During the early 1900s, pellagra was common in parts of Europe and the United States where corn was the dietary staple. Two factors contributed to this. First, the niacin in corn is bound and has a low bioavailability. Second, corn is a poor source of tryptophan, the provitamin for niacin.

One of the characteristics of pellagra is a pigmented rash that develops in areas exposed to the sunlight. Other features included diarrhea, depression, fatigue, and loss of memory.[18]

The symptoms of pellagra have been referred to as the three D's: dermatitis, diarrhea, and dementia. Death, a fourth D, can occur if the pellagra is not treated.

There have been no adverse effects from consuming niacin in the quantities found naturally in foods. However, taking higher doses of nicotinic acid in supplements can cause flushing, a vasodilatory effect that causes a reddened flush on the face, arms, and chest often accompanied by a burning, itching sensation.[18]

Other symptoms from high doses of nicotinic acid include gastrointestinal problems, liver dysfunction, and impaired glucose tolerance. Due to these adverse effects, a tolerable upper limit has been established. The adult UL is 35 mg/day.[18]

High doses of nicotinic acid (greater than 1000 milligrams per day) can lower total blood cholesterol and raise HDL cholesterol. The impact of using high doses of nicotinic acid on cardiovascular risk is not established.[19]

Although nicotinic acid is considered a nutrient, it should be approached as if it were a medication and only used under the supervision of a qualified health care provider when high pharmacological doses are used.[20]

Biotin

Biotin acts as a coenzyme in several of the energy metabolism pathways. It is also needed for the synthesis of glucose.

Biotin Sources

Good food sources of biotin include peanuts, liver, eggs, and dairy foods. Meat and fruit are poor sources of biotin.

Another source of biotin is from bacteria in the large intestine. Although bacteria-produced biotin can be absorbed in the large intestine, the relative contribution of bacteria-produced biotin towards the body's need is not known.[21]

Biotin Recommendations

The research for biotin recommendations is limited, and RDA recommendations could not be established. The biotin recommendations for all age groups are Adequate Intakes (AIs).[23]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	5 mcg*	5 mcg*		
6 mcg*	6 mcg*	7-12 months		
1-3 years	8 mcg*	8 mcg*		
4-8 years	12 mcg*	12 mcg*		
9-13 years	25 mcg*	25 mcg*		
14-18 years	25 mcg*	25 mcg*	30 mcg*	35mcg*
19-50 years	30 mcg*	30 mcg*	30 mcg*	35 mcg*

Age	Male	Female	Pregnancy	Lactation
51+ years	30 mcg*	30 mcg*		

*Indicates Adequate Intake recommendation.

Table 10.5: Biotin DRI recommended intakes[13]

Biotin Deficiencies and Toxicities

Biotin deficiency is rare but can be caused by three situations. First, eating large amounts of raw egg whites over an extended period can cause a biotin deficiency. In raw egg whites, there is a protein called avidin which tightly binds to biotin and makes it unavailable for absorption. When the egg white is cooked, the protein is denatured and broken down, thus releasing the biotin. Experimentally it has been determined a dietary intake would need to provide 30% of its calories from raw eggs to produce a biotin deficiency.[22]

For an individual that needs 2400 Calories per day, 30% would be 720 Calories, or 12 raw eggs. The second cause of biotin deficiency is a rare genetic condition that impairs intestinal biotin absorption. Third, biotin deficiency can be caused by prolonged intravenous (IV) feedings without biotin supplementation. Symptoms of biotin deficiency include hair loss, dermatitis, and depression.

A UL has not been established for biotin because no adverse effects from food and supplement intakes have been reported in humans.[23]

Pantothenic acid

Pantothenic acid is a part of coenzyme A (see Figure 6), which plays a key role in energy metabolism.

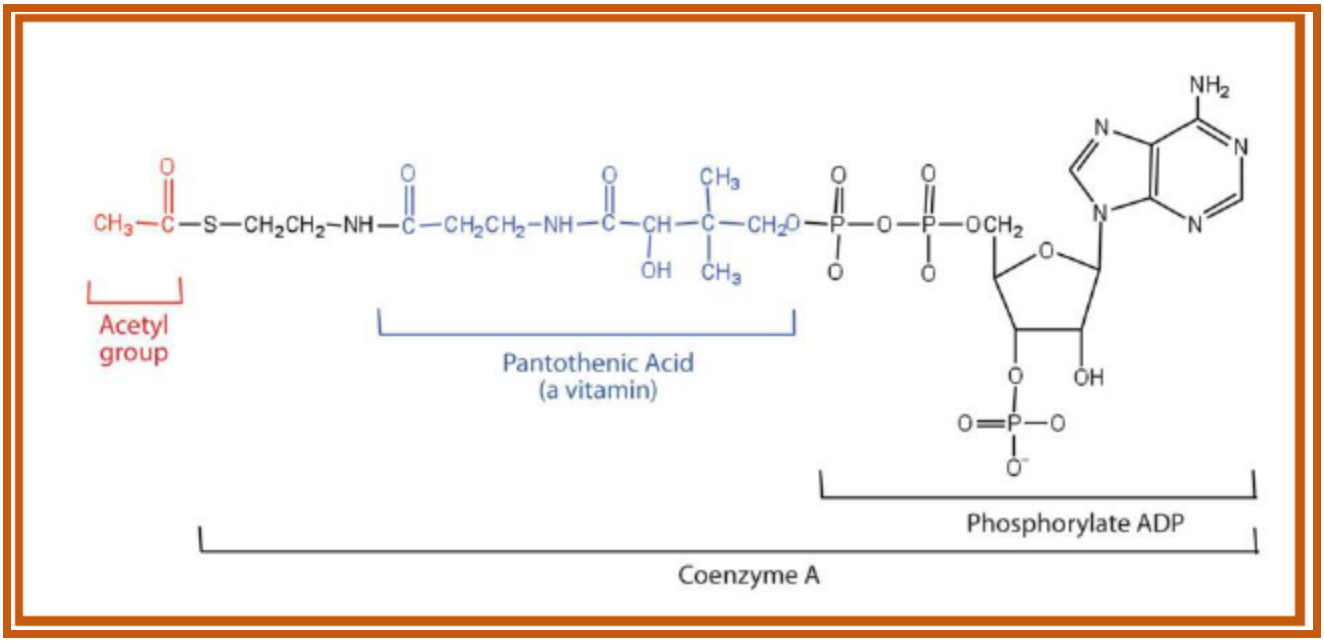


Figure 10.11: Acetyl-CoA = Coenzyme A and an acetyl group. Pantothenic acid is part of coenzyme A

Pantothenic Acid Recommendations

The research for pantothenic acid recommendations is limited, and RDA recommendations could not be established. The pantothenic acid intake recommendations for all age groups are Adequate Intakes (AIs).

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	1.7 mg*	1.7 mg*		
6-12 months	1.8 mg*	1.8 mg*		
1-3 years	2 mg*	2 mg*		
4-8 years	3 mg*	3 mg*		
9-13 years	4 mg*	4 mg*		
14-18 years	5 mg*	5 mg*	6 mg*	7 mg*
19-50 years	5 mg*	5 mg*	6 mg*	7 mg*
51+ years	5 mg*	5 mg*		

* Indicates Adequate Intake recommendation.

Table 10.6: Pantothenic acid DRI recommended intakes[13]

Pantothenic acid Sources

Pantothenic acid is found in most foods. The name pantothenic is based on the Greek word pantothen which means from all sides or everywhere.

Pantothenic acid Deficiencies and Toxicities

A pantothenic acid deficiency is rare. Symptoms include a sensation of burning in the feet, fatigue, irritability, numbness, muscle pain, and cramps.

A UL has not been established for pantothenic acid because no adverse effects from food and supplement intakes have been reported in humans or animals.[24]

Vitamin B_6

Vitamin $B_6$is the generic name for six vitamers and plays a coenzyme role to over 100 enzymes. Most of vitamin B6's coenzyme roles are involved with protein metabolism, two of which are facilitating deamination and transamination (discussed in the Protein chapter). Vitamin B_6also plays a coenzyme role in the release of glucose from glycogen breakdown, the synthesis of multiple neurotransmitters, the conversion of tryptophan to niacin, and the synthesis of heme.[25,26]

Vitamin B_6 Sources

Vitamin B_6 is found in fish, organ meats, other meats, potatoes, and several non-citrus fruits such as bananas. Ready-to-eat fortified cereals provide a significant source of vitamin B6 in the United States. Although there is vitamin B_6 in whole grains, significant amounts are lost in the refinement process and not added back in the enrichment process (refer to Chapter 5, Figure 18).

Vitamin B6 Recommendations

The DRI recommendations for vitamin B_6 are listed in Table 8.

Table 10.7: Vitamin B_6 DRI recommended intakes[13]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	0.1 mg*	0.1 mg*		
7-12 months	0.3 mg*	0.3 mg*		
1-3 years	0.5 mg	0.5 mg		
4-8 years	0.6 mg	0.6 mg		
9-13 years	1.0 mg	1.0 mg		
14-18 years	1.3 mg	1.2 mg	1.9 mg	2.0 mg
19-50 years	1.3 mg	1.3 mg	1.9 mg	2.0 mg
51+ years	1.7 mg	1.5 mg		

*Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations.

Vitamin B_6 Deficiencies and Toxicities

A severe vitamin B_6 deficiency in the United States is relatively rare.[27, 28] The importance of vitamin B_6 in infant nutrition was illustrated during the 1950s when several infants fed an infant formula low in vitamin B_6 experienced convulsions. The formula company had used excessive heat treatments to sterilize the formula, which in turn, destroyed most of the vitamin B_6 in the formula.[29]

The groups at risk for a vitamin B_6 deficiency include alcoholics and the elderly with poor dietary intakes. One sign of a deficiency is microcytic anemia because vitamin B $_6$is required for heme synthesis. Because the hemoglobin content is lower, the red blood cell has less capacity for carrying oxygen, resulting in muscle weakness, fatigue, and shortness of breath. Other signs include dermatitis, depression, and a weakened immune system.[28]

Although vitamin B_6 is a water-soluble vitamin and can be excreted in the urine, large supplementary doses (2000 to 6000 milligrams of vitamin B_6) over two to forty months can cause neuropathy and impaired motor control.[25] Supplemental doses greater than 500 milligrams per day taken over time can cause a sensory neuropathy (tingling in hands and feet). Adverse effects have not been found at doses under 200 mg per day. An adult UL of 100 mg per day has been established to prevent neuropathy problems.[27] No adverse effects have been reported with high intakes of vitamin B6 from food sources.[25]

Folate

Folate, formerly known as vitamin B_9 or folacin, is a generic term for the folate vitamers naturally occurring in food and for folic acid, the synthetic form used in fortified foods and supplements.[30,31] Folate acts as a coenzyme in the synthesis of nucleic acids (DNA and RNA) and amino acid metabolism.

Folate and Health

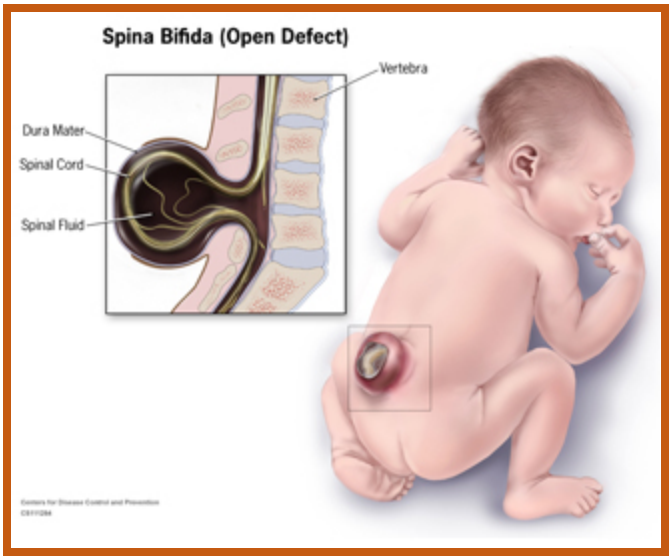


Figure 10.12: Spina bifida. Image by Centers for Disease Control and Prevention under CC0 1.0 license.

Folate is essential for the growth and specialization of cells of the central nervous system. Adequate folate intake prior to and during pregnancy can lower the risk of the baby having serious neural tube defects. The two most common neural tube defects are spina bifida (incomplete closure of the neural tube in the spine) and anencephaly (missing parts of the brain and skull). Babies born with anencephaly cannot survive. Babies born with spina bifida often experience severe physical disabilities.[32]

Although the exact cause of neural tube defects has not been identified, adequate intake of folic acid has significantly lowered the incidence of neural tube defects. The Center for Disease Control and Prevention recommends all women consume 400 micrograms of folic acid every day. This is the adult woman's RDA for folate. In order for folic acid to help prevent neural tube defects, a woman needs to start getting 400 micrograms at least one month prior to getting pregnant.[32]

Folic acid has been added to several fortified foods, especially ready-to-eat cereals. In January 1998, the U.S. Food and Drug Administration required folate to be added to enriched grains to decrease the prevalence of neural tube defects in the United States. Since the fortification of grains in 1998, the prevalence of neural tube defects in the United States has decreased approximately 30%.[33,34]

Other countries, such as Canada, Costa Rica, Chile, and South Africa have also established mandatory folic acid fortification programs.[30]

Folate Sources

Green leafy vegetables such as spinach are good sources of folate. The name folate came from the Latin word folium which means leaf or foliage. Folate is also found in liver, several vegetables, legumes, yeast, asparagus, and orange juice.



Figure 10.13: Foods high in folate. Image created by AL.

The bioavailability of folate occurring naturally in foods is variable. In general, the synthetic folic acid, found in supplements, fortified foods, and enriched grains, is approximately 1.7 times more bioavailable than the folates occurring naturally in foods. The Dietary Folate Equivalent (DFE) was devised to account for the difference in the bioavailability of folic acid and natural folates.[35]

Dietary Folate Equivalents = micrograms of food folate + (1.7 X micrograms of folic acid)

Folate Recommendations

The DRI recommendations for folate are given in dietary folate equivalents to account for the difference in bioavailability of folate found naturally in food and synthetic folic acid (see Table 9).[35]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	65 mcg DFE*	65 mcg DFE*		
7-12 months	80 mcg DFE*	80 mcg DFE*		
1-3 years	**150 mcg DFE**	**150 mcg DFE**		
4-8 years	**200 mcg DFE**	**200 mcg DFE**		
9-13 years	**300 mcg DFE**	**300 mcg DFE**		
14-18 years	**400 mcg DFE**	**400 mcg DFE**	**600 mcg DFE**	**500 mcg DFE**
19-50 years	**400 mcg DFE**	**400 mcg DFE**	**600 mcg DFE**	**500 mcg DFE**
51+ years	**400 mcg DFE**	**400 mcg DFE**		

Table 10.8: Folate DRI recommended intakes[13]

* Indicate Adequate Intake recommendation. Bolded items indicate RDA recommendations.

DFE + Dietary Folate Equivalent.

Folate Deficiencies and Toxicities

Folate plays an important role in the synthesis of DNA and RNA. Hence, rapidly dividing cells are most affected by folate deficiency. Red blood cells are continuously being synthesized in the bone marrow from dividing stem cells. A consequence of folate deficiency is macrocytic (large cell) anemia, also called megaloblastic anemia (see Figure 7). Without adequate folate, red blood cells are unable to produce DNA and RNA fast enough to divide properly. The result is fewer red blood cells that are large.

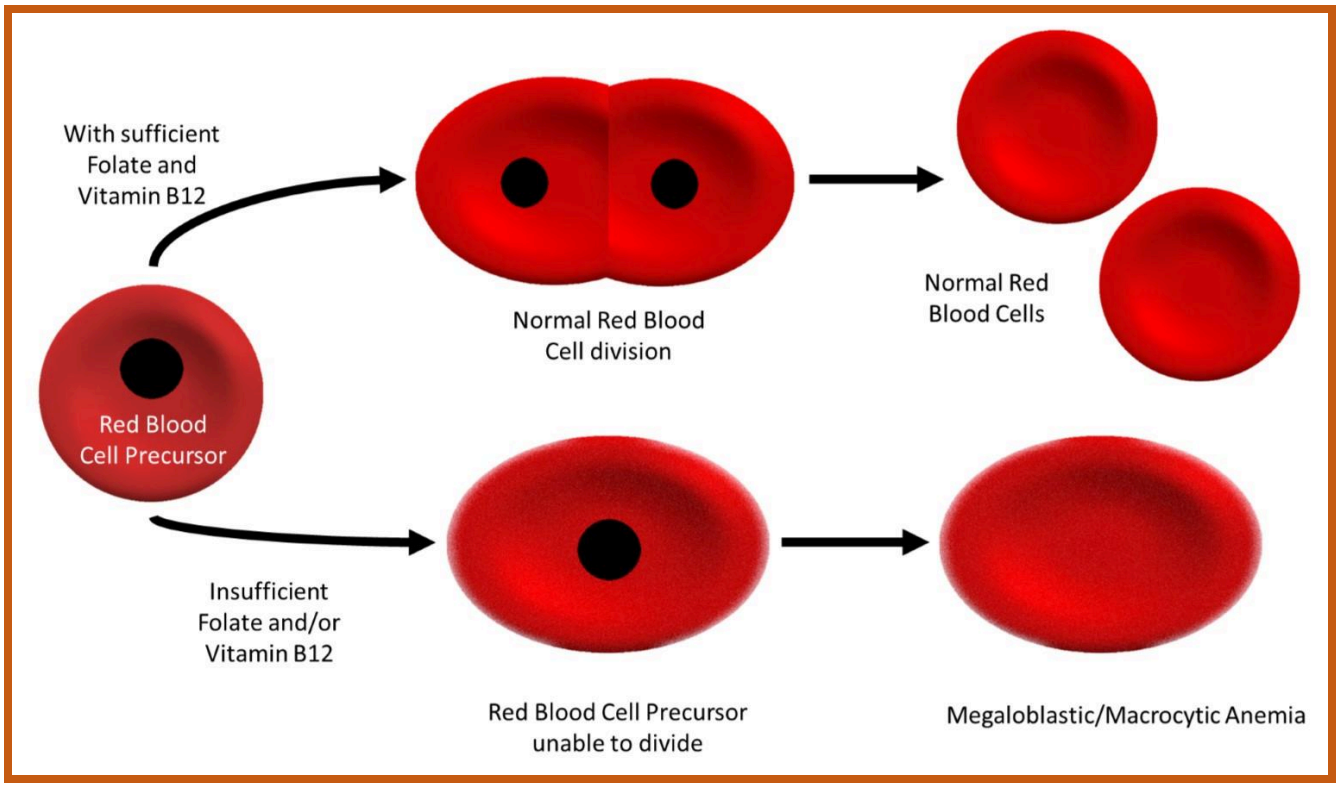


Figure 10.14: Megaloblastic/macrocytic anemia causes by insufficient folate and/or vitamin B_{12}

Megaloblastic anemia is also an early symptom of a vitamin B_{12} deficiency. This is the same type of anemia that occurs with a folate deficiency. If a person takes large doses of folic acid, they will not develop megaloblastic anemia from a vitamin B12 deficiency. However, folic acid will not prevent the progressive damage to the neurological system that is caused by a more severe vitamin B_{12} deficiency. Hence, large doses of folic acid will hide or mask the early stages of a vitamin B_{12} deficiency. To avoid this, a UL for folic acid was established. No adverse effects have been associated with excess folate from food.[35]

Vitamin B_{12}

Vitamin B_{12}, also called cobalamin, is unique among the vitamins because it contains a mineral (cobalt). It also has the most complex structure of the vitamins. Vitamin B_{12} has several vitamers. The two vitamers actively used by humans are methylcobalamin and 5-deoxyandeosylcobalamin. Cyanocobalamin (the form of vitamin B_{12} usually found in supplements) and hydroxocobalamin can be readily converted by the body to these forms.[36]

Vitamin B_{12} functions as a coenzyme for two enzymes and plays a role in fat and protein catabolism, and maintaining the myelin sheath on nerve cells. Vitamin B_{12} also works with folate in the synthesis of methionine (an amino acid) from homocysteine, and the synthesis of DNA and RNA. These two vitamins depend on each other for activation in these functions. Early deficiency symptoms in vitamin B_{12} often has similar health consequences as a folate deficiency.

Vitamin B_{12} Absorption

The absorption of vitamin B_{12} is a complex process (see Figure 8). Vitamin B_{12} found naturally in animal products is bound by the food proteins and is not bioavailable for absorption. In the stomach, hydrochloric acid and pepsin (a protein digestive enzyme) digests the food proteins and releases vitamin B_{12}. While in the stomach, the freed vitamin B_{12} then binds with the R-

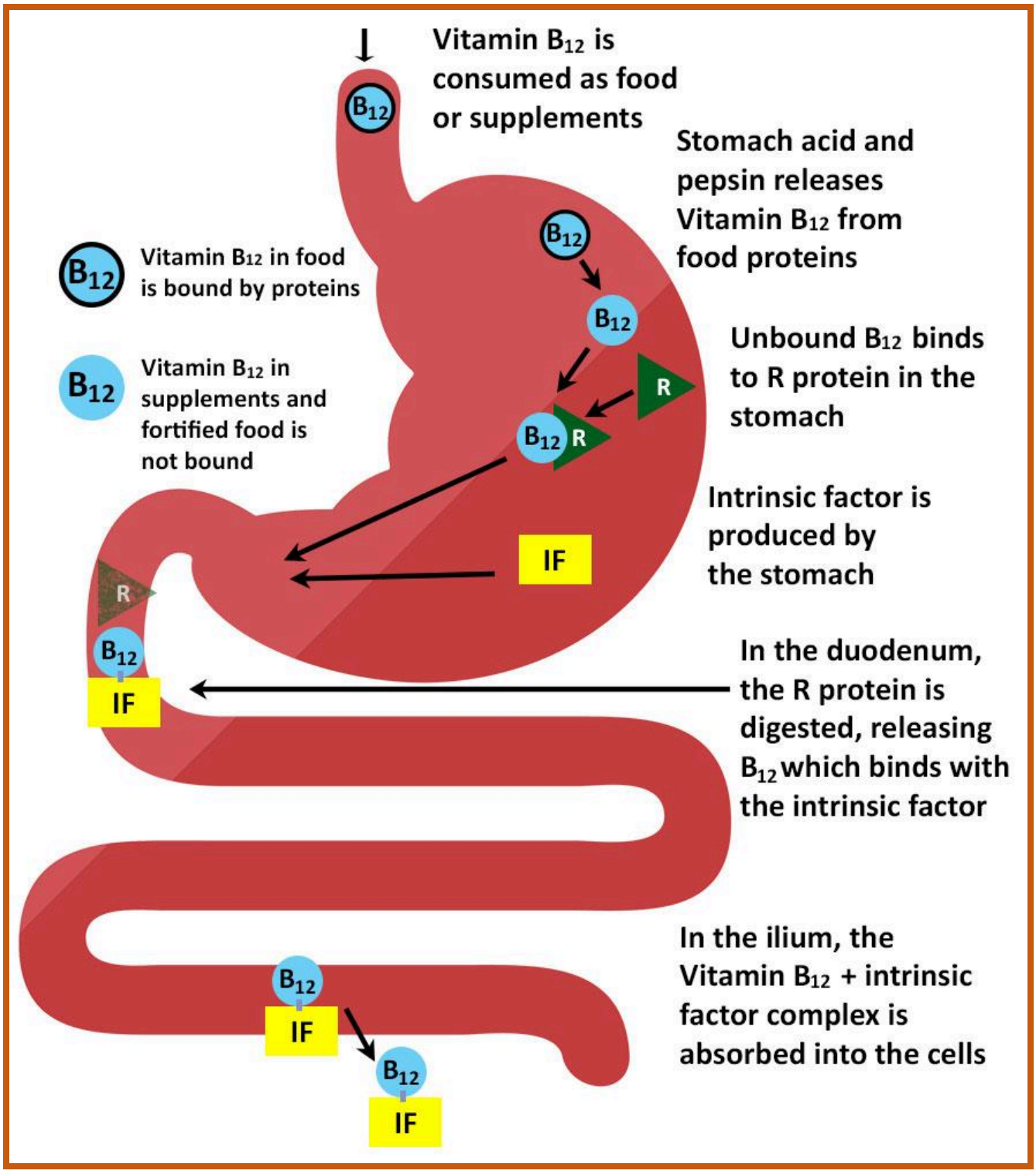


Figure 10.15: Absorption of Vitamin B.$_{12}$

protein (produced by the salivary glands). The stomach also produces **intrinsic factor**, a substance necessary for good vitamin B_{12} absorption.

The vitamin B_{12}-R-protein complex then leaves the stomach and enters the duodenum. The pancreatic proteases cleave the R protein from vitamin B_{12} in the duodenum. Vitamin B_{12} then binds to the intrinsic factor and travels to the ilium. The vitamin

B_{12}-intrinsic factor complex is then absorbed into the cells lining the ilium. Without the intrinsic factor, only one percent of the vitamin B_{12}can be absorbed.[37]

Vitamin B_{12} Sources

Plants and animals cannot synthesize vitamin B_{12}. Only certain bacteria can synthesize it. Hence, almost all plant foods do not provide a source for vitamin B_{12} naturally.[36] Reliable sources of vitamin B_{12} are found in meat and animal products. Animals consume vitamin B_{12} produced by bacteria in the soil. Also, ruminant animals can absorb vitamin B_{12} produced by bacteria within their digestive system.[38] Foods such as ready-to-eat cereals and soy milk are often fortified with vitamin B_{12}.

Vitamin B_{12} Recommendations

The vitamin B_{12} adult RDA is only 2.4 micrograms a day; this is the lowest quantity needed for all the vitamins (see Table 10 for recommended intakes). It is estimated that 10 to 30 percent of people over 50 years of age have atrophic gastritis (inflammation of the stomach lining) which results in low stomach acid secretion. Since this can increase the likelihood of food-bound vitamin B_{12} malabsorption, it is recommended for individuals over the age of 50 years to obtain their vitamin B_{12} from either a fortified food (such as ready-to-eat cereals) or a supplement.[37]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	0.4 mcg*	0.4 mcg*		
7-12 months	0.5 mcg*	0.5 mcg*		
1-3 years	0.9 mcg	0.9 mcg		
4-8 years	1.2 mcg	1.2 mcg		
9-13 years	1.8 mcg	1.8 mcg		
14-18 years	2.4 mcg	2.4 mcg	2.6 mcg	2.8 mcg
19-50 years	2.4 mcg	2.4 mcg	2.6 mcg	2.8 mcg
51+ years	2.4 mcg	2.4 mcg		

Table 10.9: Vitamin B12 DRI recommended intakes[13]

* Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendation.

Vitamin B_{12} Deficiencies and Toxicities

Early stages of a vitamin B_{12} deficiency are characterized by tiredness, constipation, weight loss, and megaloblastic anemia (see Figure 9). As the severity of the deficiency continues, irreversible damage to the neurological system can cause numbness and tingling of the hands and feet, memory loss, disorientation, and dementia.

Three key groups are at risk of developing a vitamin B_{12} deficiency. First, individuals with atrophic gastritis, usually older adults, do not absorb vitamin B_{12} found naturally in foods because food proteins bind it. It is recommended individuals older than 50 years get their vitamin B_{12} from fortified foods or supplements. Second, people who no longer make intrinsic factor.

The megaloblastic anemia caused by a lack of intrinsic factor is called pernicious anemia. These individuals may get their vitamin B_{12} either by an intramuscular injection or by taking a megadose vitamin B_{12} supplement (one percent of the vitamin B_{12} can be absorbed without the intrinsic factor). The third group at risk are vegan vegetarians. It is recommended they consume either fortified foods or take a vitamin B_{12} supplement.

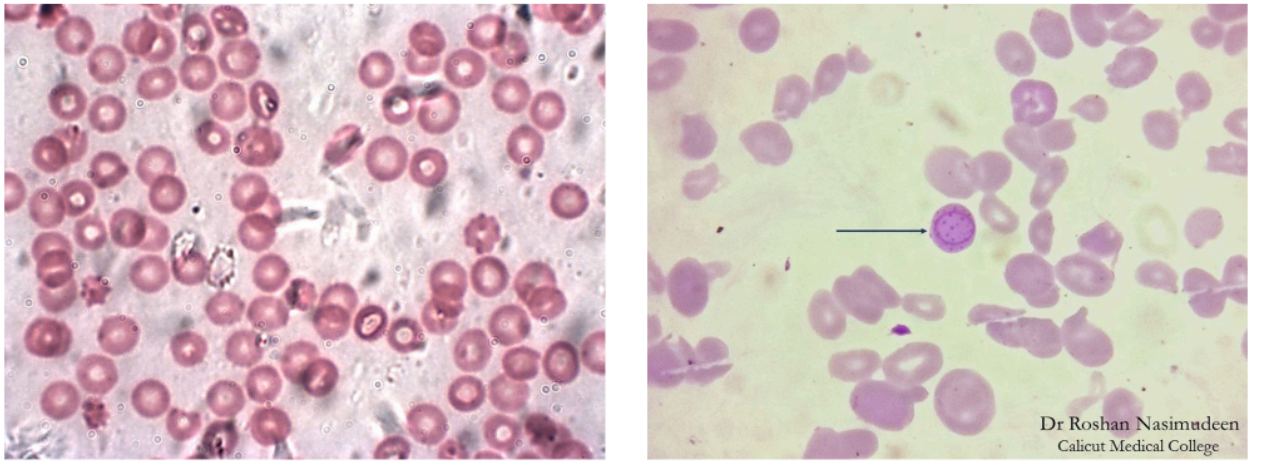


Figure 10.16: Comparison of normal and megaloblastic red blood cells. Red Blood Cells by John Alan Elson under CC BY-SA 3.0 license with edits. Megaloblastic Red Blood Cells by Dr. Roshan Nasimudeen under CC BY-SA 4.0 license with edits.

A UL has not been established for vitamin B_{12} because no adverse effects from excess vitamin B_{12} from food or supplements have been observed.[37]

Do B-Vitamin Supplements Provide an Energy Boost?

Although some marketers claim taking mega-doses of B-vitamins in a supplement boosts energy and performance, there is no evidence that supplementation with vitamins enhance performance except in cases where pre-existing deficiencies exists.[7] The perception of more energy from energy-boosting supplements usually comes from the high amount of caffeine, other herbal stimulants, and added sugars that accompany the high doses of B-vitamins. Although the B-vitamins are needed to support energy metabolism and growth, if a person has adequate amounts in their dietary intake, taking in more than required does not supply you with more energy. An analogy of this phenomenon is the gas in your car. Without gas, the car cannot operate. Will filling the tank until gas is running all over the ground improve your car's ability to operate at a faster speed? 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. Buyers of mega-dose B-vitamin supplements beware; B-vitamins are not stored in the body and all excess will be flushed down the toilet along with the extra money spent.

Vitamin C

Vitamin C, also known as ascorbic acid, is a water-soluble vitamin essential in the diet for humans, although most other mammals can readily synthesize it. It was the first vitamin to be scientifically studied. In 1747, James Lind was on a ship where sailors began to develop scurvy. He hypothesized scurvy was caused by the putrefaction of the body and could be cured by certain acids. To test his hypothesis, Lind divided twelve sailors with about the same degree of scurvy into six groups of two. They all were given the same basic diet. In addition, group one was given a quart of cider each day, group two received twenty-five drops of elixir vitriol (sulfuric acid) three times a day, group three two tablespoons of vinegar three times a day, group four half a pint of seawater, group five two oranges and one lemon, and group six a spicy paste plus barley water. The group receiving oranges and lemons recovered from the scurvy.[39] The name ascorbic acid comes from the prefix "a" meaning no and the word "scorbutus" meaning scurvy.

Functions

Antioxidant

Vitamin C's ability to easily donate electrons makes it an effective antioxidant to neutralize several free radicals in the body. It is the primary water-soluble, non-enzymatic antioxidant in plasma and the tissues. Vitamin C also helps protect lipids from oxidative damage by aiding in the regeneration of vitamin E, a fat-soluble vitamin that also functions as an antioxidant.[40]

Collagen Synthesis

Vitamin C is necessary for the synthesis of healthy collagen in the body. Collagen is the most abundant protein in the body and is an essential component of connective tissue. Cells are held together in part by the collagen that surrounds them. When a person has a wound, collagen helps bind the tissues together in the healing process. The thin capillary walls are supported by collagen.[28]

Collagen is made of three linear proteins that twist together to form a triple helix. Vitamin C plays a key role in adding hydroxyl (-OH groups) to the protein so crosslinks can form to stabilize the proteins (see Figure 10).

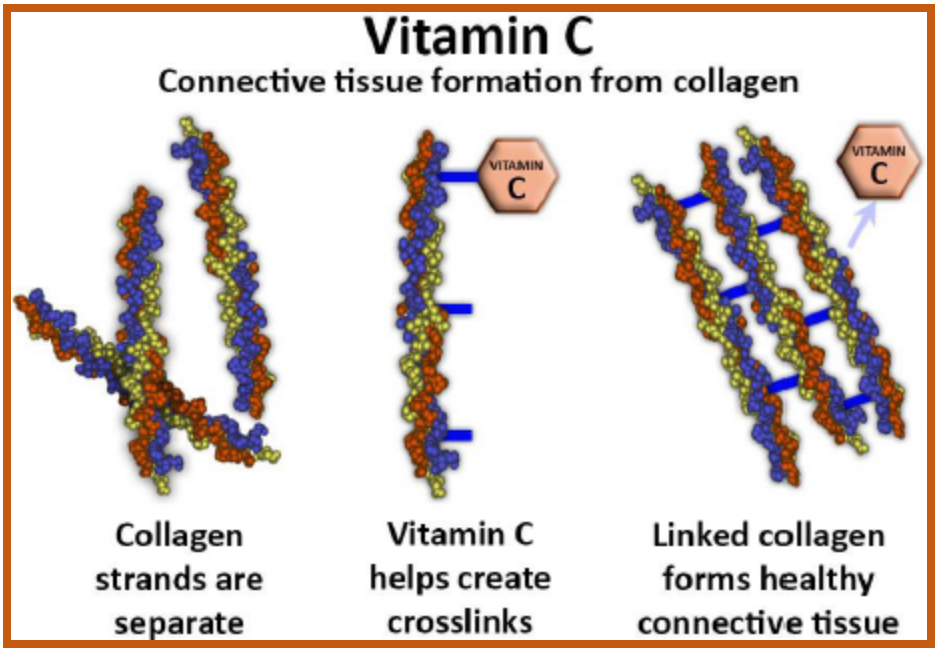


Figure 10.17: Vitamin C and healthy collagen synthesis

Iron Absorption

Non-heme iron absorption can increase by two- to threefold in the presence of 25 to 35 milligrams of vitamin C.[41] Vitamin C reduces the ferric iron (Fe3+) to the more bioavailable ferrous iron (Fe2+).

Vitamin C and Health

Cardiovascular Disease

Epidemiological studies indicate high intakes of fruits and vegetables are associated with a lower risk for cardiovascular disease. This association may be partly attributable to vitamin C, because 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. However, most clinical trials have not shown a beneficial effect of vitamin C supplementation on the prevention of cardiovascular disease.[42]

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.[69,70,71,72]

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.

Common Cold

Many people increase vitamin C intake either from diet or supplements when they have a cold. Others take vitamin C supplements routinely to prevent colds. Contrary to these popular practices, there is no good evidence that vitamin C reduces the risk of developing a cold in the general population. However, in people undergoing heavy physical stress, such as marathon runners and soldiers in subarctic conditions, vitamin C supplementation ranging from 250 milligrams to 1000 milligrams per day reduced the cold incidence by 50%.[40, 42]

Also, when people in the general population took vitamin C regularly prior to a cold, the duration of the cold was reduced 14% in children and 8% in adults. This reduction in duration was not observed when vitamin C was taken after the cold symptoms occurred.[40]

Vitamin C Sources

Fruits and vegetables are the best sources of vitamin C. Citrus fruits, tomatoes, and potatoes are major contributors of vitamin C in the United States. 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 destroyed. In order to maximize your vitamin C intake from foods, you can eat fruits and vegetables raw, microwaved, or lightly steamed.

There is a 70 to 90 percent absorption of vitamin C from food when consumed in amounts of 30 to 100 milligrams at a time. The absorption of vitamin C decreases to less than 50 percent when 1000 milligrams or more are consumed at one time.[28]

Vitamin C Recommendations

The DRI vitamin C recommended intakes are set to maintain near-maximal tissue concentrations of vitamin C and to provide antioxidant protection (see Table 10). Vitamin C's effectiveness as a free radical scavenger motivated the Institute of



Figure 10.18: Foods high in vitamin C. Created by AL.

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.[43]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	40 mg*	40 mg*		
7-12 months	50 mg*	50 mg*		

Age	Male	Female	Pregnancy	Lactation
1-3 years	15 mg	15 mg		
4-8 years	25 mg	25 mg		
9-13 years	45 mg	45 mg		
14-18 years	75 mg	65 mg	80 mg	115 mg
19-50 years	90 mg	75 mg	85 mg	120 mg
51+ years	90 mg	75 mg		

Table 10.10: Vitamin C DRI recommended intakes[13]

* Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations.

Vitamin C Deficiencies and Toxicities

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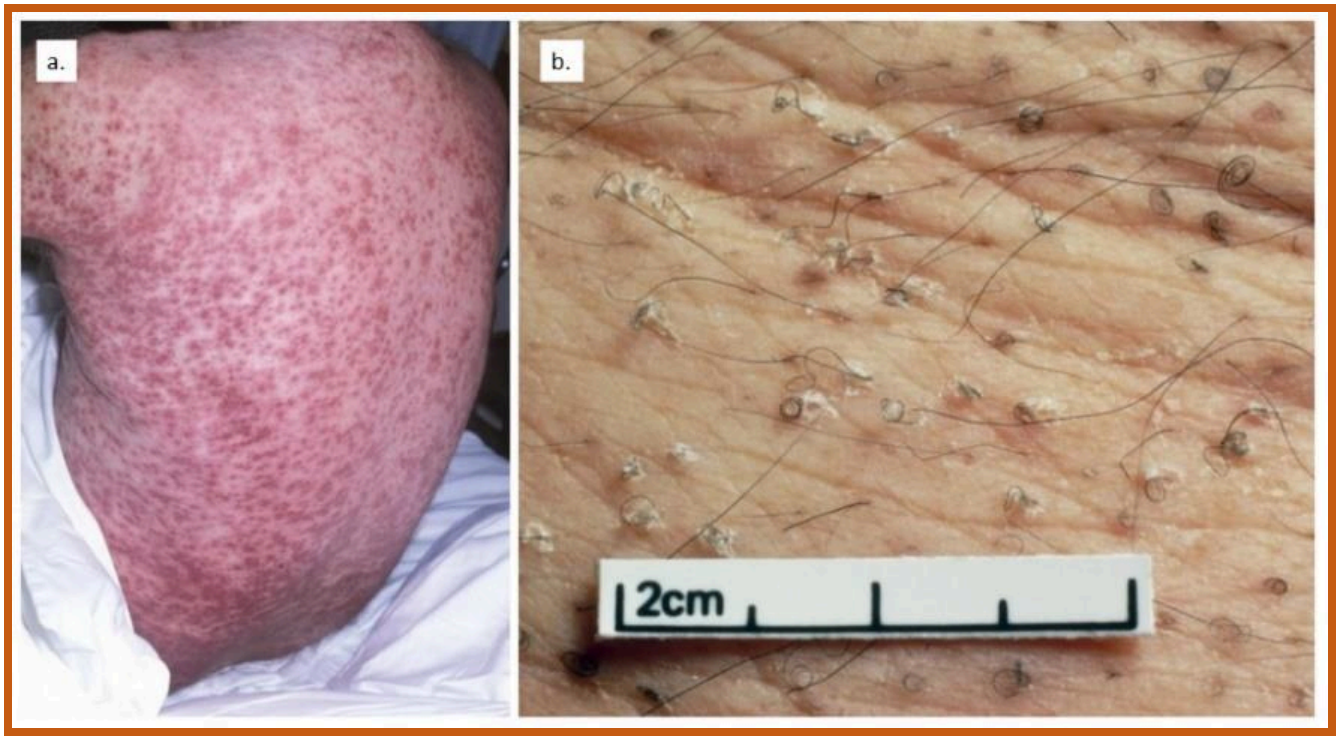


Figure 10.19: Scurvy symptoms include (a) petechiae (small red dots caused by ruptured capillaries) and (b) corkscrew hair.

A vitamin C deficiency causes scurvy. The symptoms of scurvy can appear after three months of a severe or total vitamin C-free diet.[42]

Early symptoms include fatigue and aching limbs. Later symptoms are a result of defective collagen development and include bleeding gums, skin disorders, painful joints, petechiae (small red dots caused by capillary breakdown and bleeding), and corkscrew hair (see Figure 11). Other symptoms include weakness, depression, and increased susceptibility to infections.[43, 44]

Although current evidence indicates high doses of vitamin C (greater than 3000 milligrams per day) has low toxicity potential for the healthy person, there may be adverse gastrointestinal effects such as diarrhea, nausea, or cramping. The adverse effects are attributed to the decrease in vitamin C absorption when large doses are consumed. The unabsorbed vitamin C can cause an osmotic diarrhea. An adult UL of 2,000 milligrams per day of vitamin C has been established for healthy people based on the adverse intestinal effects.[43]

People at risk for iron-overload (such as those with hemochromatosis) are cautioned against taking high doses of vitamin C because of the potential for increased non-heme iron absorption and possible vitamin C pro-oxidant effects on the excessive iron stores in the body.[43]

Key Takeaways

- *Many water-soluble vitamin deficiencies are linked to specific diseases, such as beriberi (thiamin), pellagra (niacin), and scurvy (Vitamin C).*
- *Folate is essential for DNA and RNA synthesis and is critical for pregnant women to prevent neural tube defects like spina bifida in the developing baby.*
- *Vitamin B12 is unique because it is primarily found in animal products and its absorption requires a special protein called intrinsic factor.*
- *Most of the B-vitamins function as coenzymes that are crucial for a wide range of metabolic processes, including converting carbohydrates, proteins, and fats into energy.*
- *While most water-soluble vitamins are not stored in the body, excessive intake of Vitamin B6 can cause nerve damage, and high doses of Vitamin C may lead to adverse gastrointestinal effects.*

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4.4

Fat-Soluble Vitamins

10.4 Fat-Soluble Vitamins

Vitamin A

Although the vitamin A deficiency, night blindness, was described as early as 1500 BC by the Egyptians and was treated by dropping juice from liver (an excellent vitamin A source) onto the surface of the eye, it was not until 1913 that vitamin A was identified by McCollum and Davis. [2]

Vitamin A is found in food in both the active form of the vitamin and in a provitamin form which can be converted by the body to the active vitamin. The active vitamin A is referred to as the preformed vitamin A and has three vitamers (retinol, retinal and retinoic acid) that are collectively referred to as the retinoids. The vitamin A provitamins come from the carotenoid family. There are over 600 members of the carotenoid family, but not all of them can be converted by the body to vitamin A. The three most important members of the carotenoid family that are vitamin A provitamins are beta-carotene, alpha-carotene, and beta-cryptoxanthin.

Vitamin A Functions

Vitamin A has several roles in the body, which include maintaining vision, immunity, reproduction, growth and cellular differentiation (helping stem cells become specialized cells). The active forms of vitamin A (retinol, retinal and retinoic acid) are structurally similar but dissimilar enough to allow them to operate differently in the body.

Vision

Vitamin A can impact vision in two separate ways. The retinoids are needed by the retina (located at the back of the eye) to be able to see in dim light and by the cornea and surrounding membranes (located at the front of the eye) for normal cell differentiation and mucus production (see Figure 12).

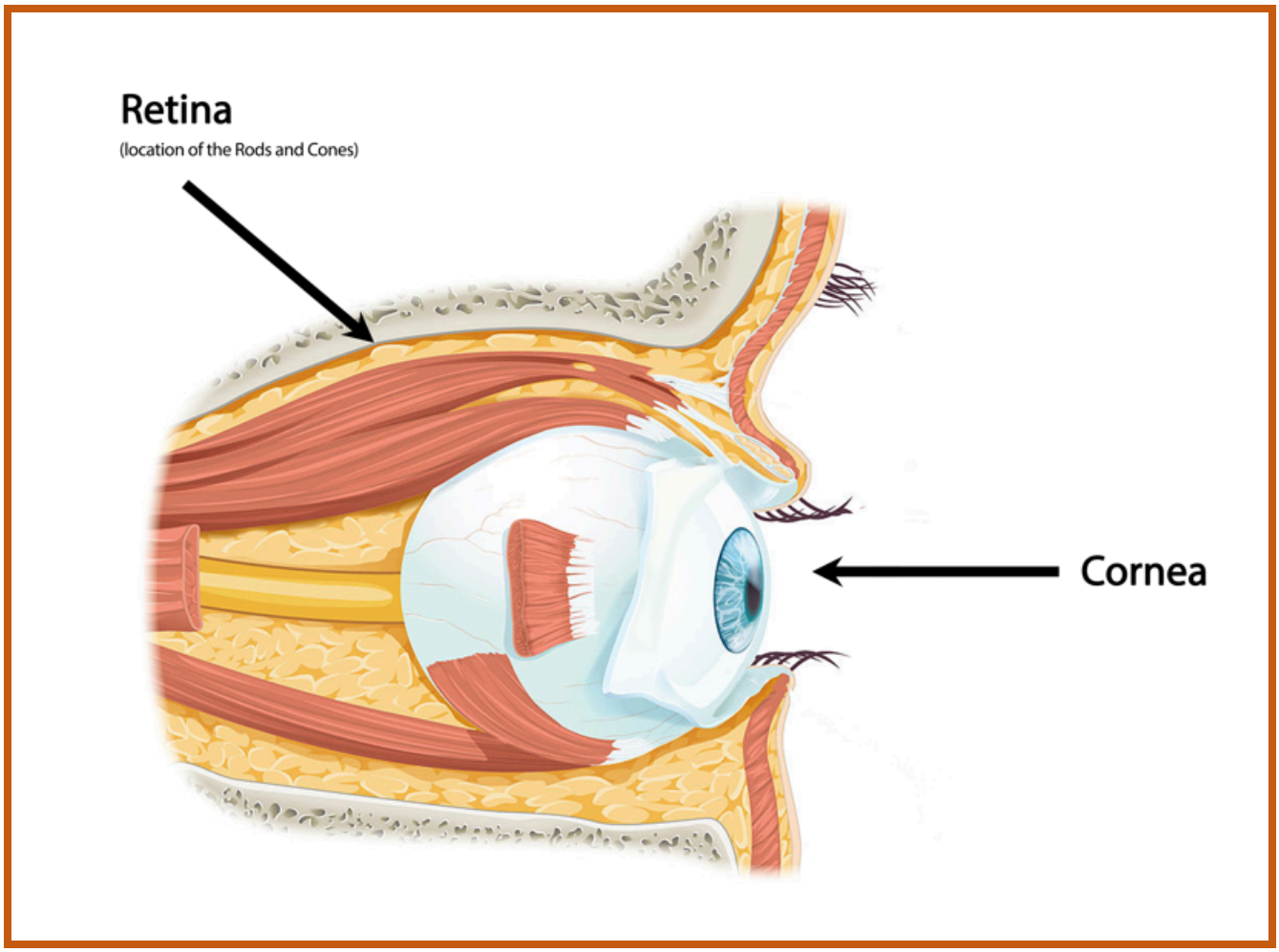


Figure 10.20: Structure of the eye. Image by OpenStax College under CC BY 3.0 license.

The retinal form of vitamin A is required by the eye to be able to see black and white vision. The eye's retina has two types of cells for vision, the rod cells for black and white vision in dim light and the cone cells for color vision. In the rod cells, a substance called rhodopsin plays an important role in black and white vision. Rhodopsin is made from the vitamin retinal and a protein called opsin. When light hits the rod cells, the retinal separates from the opsin and sends a visual signal to the optic nerve of the brain. To continue seeing in dim light, the rhodopsin needs to be reformed with new retinal which can take a few moments. You may have experienced this if you were in a low light setting and had a bright flash of light to your eyes. You were temporarily blinded until your eyes could make more rhodopsin.

Cell Growth and Differentiation

Retinoic acid plays a significant role in growth and development. At the genetic level, retinoic acid influences gene expression which in turn influences cell differentiation.

Immunity

During the 1970s, researchers conducting vitamin A studies in Indonesia noted that children with vitamin A deficiency died at much higher rates from infectious disease. [46] This observation led scientists to hypothesize that supplementing vitamin A in the diet of these children might reduce disease-related mortality. In subsequent studies, targeted populations of children were administered vitamin A supplements, and the death rates from measles and diarrhea declined by up to 54 percent.[46] 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 and the number of fatalities. Soon after the results of these studies were published, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) commenced worldwide campaigns against vitamin A deficiency. UNICEF estimated that over a half of a billion vitamin A capsules have been distributed and have prevented over 350,000 childhood deaths each year. [46]

Vitamin A's role in the prevention of infectious disease is still being unraveled. It is apparent that through its interaction with cellular and nuclear receptors it affects the growth, development, and function of immune cells. [47] Vitamin A is also important in maintaining the integrity of epithelial tissues and in the production of mucus, both of which are essential for the maintenance of a barrier against infectious diseases. There are likely other ways adequate vitamin A protects against invaders, and while the exact mechanisms are not known yet, it is clear that low vitamin A intakes result in increased death rates from infection.

Carotenoid's Health Benefits

Since only a small portion of the provitamin A carotenoids are converted to vitamin A, much of those ingested stays intact in the body tissues. These carotenoids have health benefits independent of their vitamin A potential such as beta-carotene's antioxidant capabilities. The carotenoid family also has compounds such as lutein, lycopene, and zeaxanthin. These carotenoids are not provitamins for vitamin A but are recognized for their health-promoting properties.48 Having elevated levels of these compounds in body tissues are associated with a reduced risk for eye problems with aging (such as cataracts) and chronic diseases such as cardiovascular disease and cancer.

Vitamin A Sources

The retinoids (preformed vitamin A) are found in animal products such as liver, fish oils, eggs, and milk. Most of the provitamin A carotenoids come from plants that are either orange/yellow or very dark green in color. For example: orange/yellow plant foods like carrots, sweet potatoes and pumpkin; and dark green vegetables like spinach, kale and broccoli. [49]



Figure 10.21: Animal products such as liver is the source for preformed vitamin A. Image by Peachyeung316 under CC BY-SA 4.0 license.



Figure 10.22: Most of the provitamin A comes from plant products such as carrots. Created by AL.

Both the preformed vitamin A (the retinoids) and provitamin A (carotenoids) in foods are considered vitamin A sources. A unit of measure called retinal activity equivalent (RAE) was developed to account for the potential vitamin A from the provitamins beta-carotene, alphacarotene, and cryptoxanthin. The conversion units for these provitamins are:

- 12 micrograms of beta-carotene = 1 microgram of retinol activity equivalent (RAE)
- 24 micrograms of alpha-carotene = 1 microgram of retinol activity equivalent (RAE)
- 24 micrograms of cryptoxanthin = 1 microgram of retinol activity equivalent (RAE)50

The total amount of vitamin A in the meal is the actual vitamin A in the animal products plus the estimated amount that will be derived from converted provitamins (see Table 12).

Food	Retinol	Beta-carotene	Alpha-carotene	Crypto-xanthin	RAE
Beef liver, 3 oz raw	4948 mcg	232 mcg	11 mcg	13 mcg	4968 mcg
Cod liver oil, 1 Tablespoon	4080 mcg	0 mcg	0 mcg	0 mcg	4080 mcg
Cooked carrot, 1/2 cup	0 mcg	6499 mcg	2945 mcg	0 mcg	665 mcg
Apricots, 1 cup sliced	0 mcg	1805 mcg	31 mcg	172 mcg	158 mcg

Source: USDA Nutrient Database

Table 10.11: Dietary sources for Vitamin A

Vitamin A Recommendations

The Dietary Reference Intake recommendations for vitamin A are given in micrograms of retinol activity equivalents (RAE).[50] In the United States, older versions of the Food Label listed the amount of vitamin A in International Units which is a measure of the vitamin's biological activity. The conversion factor for vitamin A is 1 IU = 3.33 mcg retinol.

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	400 mcg RAE*	400 mcg RAE*		
7-12 months	500 mcg RAE*	500 mcg RAE*		
1-3 years	300 mcg RAE	300 mcg RAE		
4-8 years	400 mcg RAE	400 mcg RAE		
9-13 years	600 mcg RAE	600 mcg RAE		
14-18 years	900 mcg RAE	700 mcg RAE	750 mcg RAE	1200 mcg RAE
19-50 years	900 mcg RAE	700 mcg RAE	770 mcg RAE	1300 mcg RAE
51+ years	900 mcg RAE	700 mcg RAE		

* Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations. RAE = retinal activity equivalent.

Table 10.12: Vitamin A DRI recommended intakes[13]

Vitamin A Deficiency and Toxicity

Deficienc

A clinical vitamin A deficiency is rare in the United States. However, it is more common in many developing countries because of limited access to animal-based food sources (for preformed vitamin A) and not consuming plant foods with provitamin A (primarily beta-carotene).[49]

One of the first signs of a vitamin A deficiency is night-blindness, which is the inability to see in low light. Night-blindness is easily corrected by consuming adequate vitamin A. As the deficiency becomes more severe, there is a decrease in the production of mucus-secreting cells that lubricate the eye. This deficiency causes dryness of the eye which progresses to deterioration of the cornea, the appearance of white patches called Bitot's spots, and eventually leads to total blindness called xerophthalmia. Vitamin A deficiency is one of the leading causes of preventable blindness in children.[49, 51]

In addition to impacting vision, a vitamin A deficiency can depress the immune system, decrease growth, impair reproduction, and lower bone mineral density. Furthermore, a deficiency can result in a condition called follicular hyperkeratosis, which is a buildup of the keratin (a fibrous protein) in hair follicles creating a bumpy, goose flesh appearance to the skin.

Toxicity

Vitamin A is well recognized as having a defined and serious toxicity. Symptoms may vary depending on if the toxicity is caused by extremely high amounts (over 15,000 micrograms) of vitamin A in a short period (acute toxicity) or intakes (over 2,700 micrograms) daily of vitamin A over an extending period (chronic toxicity).[52]

Up to this point, it has been clear that serious adverse effects do not arise until preformed vitamin A intakes are well over the UL. During pregnancy, adherence to the vitamin A guidelines is important. Doses above 3,000 micrograms per day (10,000 IU) 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 they are taking to assure the amount is below the UL, and be aware of the vitamin A content of foods. Because of this noted concern, most producers of prenatal supplements meet all or part of the vitamin A requirement by using beta-carotene instead of actual vitamin A in their supplement.[53]



Figure 10.23: Polar Bear. Created by AL.

Today, most vitamin A toxicity cases occur from excessive supplementation of vitamin A. Historically, there are cases of explorers consuming one meal with polar bear liver (or seal liver) and experiencing symptoms of irritability, vomiting, peeling skin, and death.[54] When analyzed it was found that raw polar bear liver contains up to 500,000 micrograms of vitamin A in a 3-ounce portion which drastically exceeds the current adult UL of 3,000 micrograms.[54] In comparison, 3-ounces of raw beef liver has only 4,000-5,000 micrograms of vitamin A. Consuming beef liver in moderation has not been associated with adverse side effects.

Interestingly, it is not possible to experience a vitamin A toxicity from any of the provitamins regardless of the level of intake. The body will stop the conversion of vitamin A from the provitamin when the body has adequate amounts of vitamin A. The most distressing problem that can occur with high intakes of carotenoids is the skin can take on an orange hue as the carotene deposits in the fat layers under the skin. When intake of carotenoids is decreased, the skin color will return to normal.[52]

Vitamin D



Figure 10.24: Comparison of normal hand (left) with hand of person with carotenemia (right). Image by Norge0209 under CC BY 3.0 license.

Vitamin D, also known as calciferol, has two dietary vitamers, vitamin D2 (ergocalciferol) found in a limited number of plants and vitamin D_3 (cholecalciferol) found in a small number of animal products. The human body can also make vitamin D_3 from cholesterol when the skin is exposed to the sun's ultraviolet B (UVB) rays.

Vitamin D is often referred to as a hormone because of the body's ability to synthesize it and because it has hormone-like functions when in its active form. The reason vitamin D is also classified as a vitamin is that the amount produced by the body may be inadequate under certain conditions. When this happens, it becomes essential to consume vitamin D either in food or a supplement.[55]

Vitamin D Activation and Functions

Vitamin D_2 and vitamin D_3 are not biologically active in the body. Activation of vitamin D requires two steps, first at the liver and then at the kidneys. Enzymes in the liver add a hydroxyl (OH) group to vitamin D's carbon number 25 to form 25 hydroxy-vitamin D (also known as calcidiol). Then the 25 hydroxyl vitamin D travels to the kidneys where another hydroxyl group is added to carbon number 1 to form the active vitamin, 1, 25 dihydroxy vitamin D (also known as calcitriol) (see Figure 13).[56]

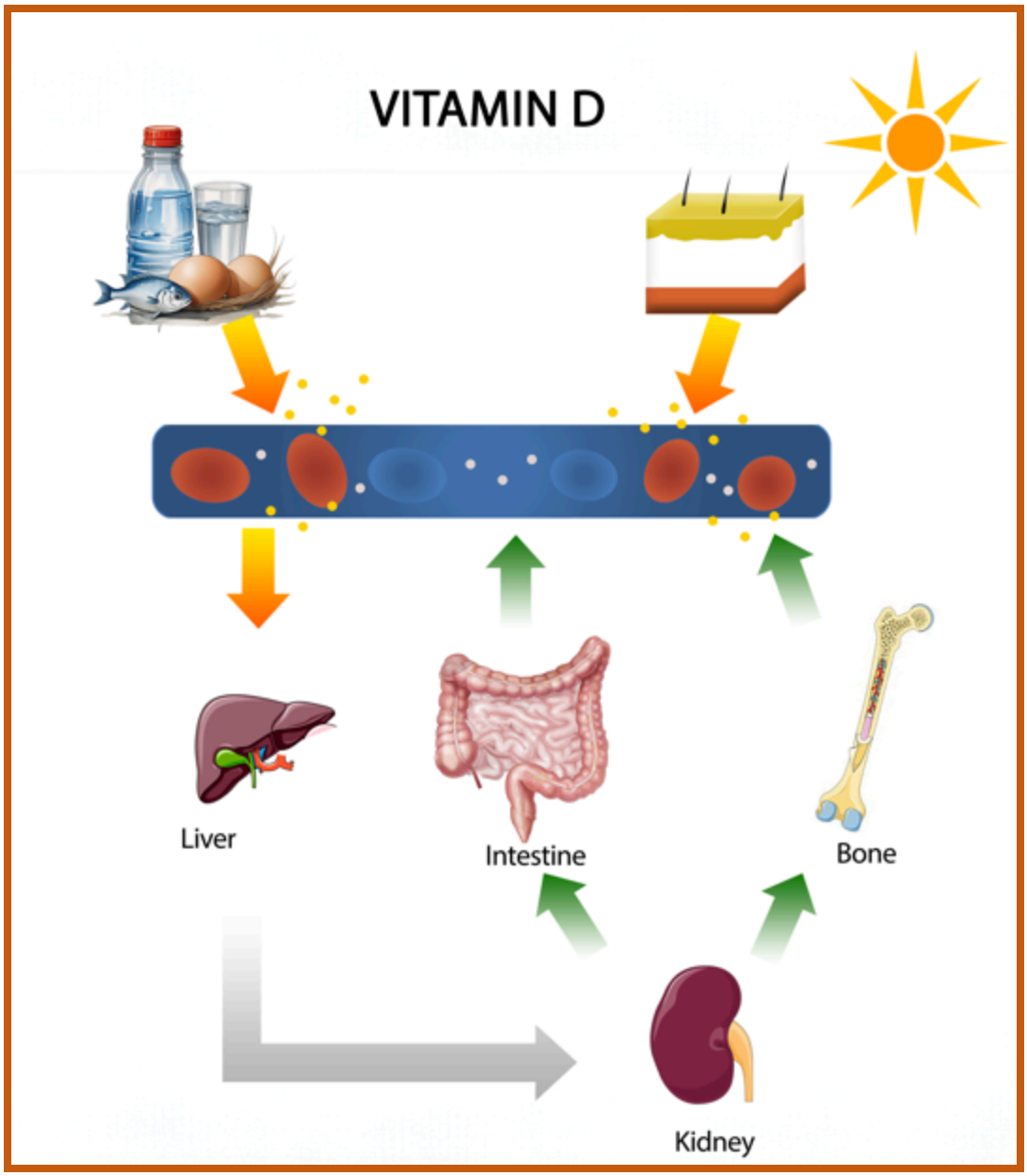


Figure 10.25: Activation of vitamin D. Liver image by Laboratoires Servier under CC BY-SA 3.0 license with edits. Kidney image by Laboratoires Servier under CC BY-SA 3.0 license with edits. Bone Image by Laboratoires Servier under CC BY-SA 3.0 license with edits.

A key function of the activated vitamin D (calcitriol) is to regulate blood calcium levels. Calcitriol increases calcium absorption by promoting the synthesis of calcium transporter proteins in the cells lining the small intestine. When the blood levels of calcium are low, calcitriol and the parathyroid hormone will act to increase levels of calcium in the blood by decreasing the amount of calcium lost in the urine and promoting the bones to release calcium.

Calcitriol's action to increase calcium absorption from the small intestine is crucial for good bone health. When calcitriol levels are low, the absorption of calcium from food and supplements decreases from 25-33 percent to less than 10-15 percent.[57]

Other health benefits have been linked to having adequate vitamin D, from decreased cardiovascular disease to the prevention of infection. Furthermore, observational studies and evidence from laboratory studies conducted in cells, tissues, and animals suggest vitamin D inhibits the growth of certain colorectal and breast cancers, lowers risk for autoimmune

diseases such as rheumatoid arthritis and multiple sclerosis, reverses atherosclerosis, lowers high blood pressure, and increases insulin secretion.[58]

Vitamin D Sources

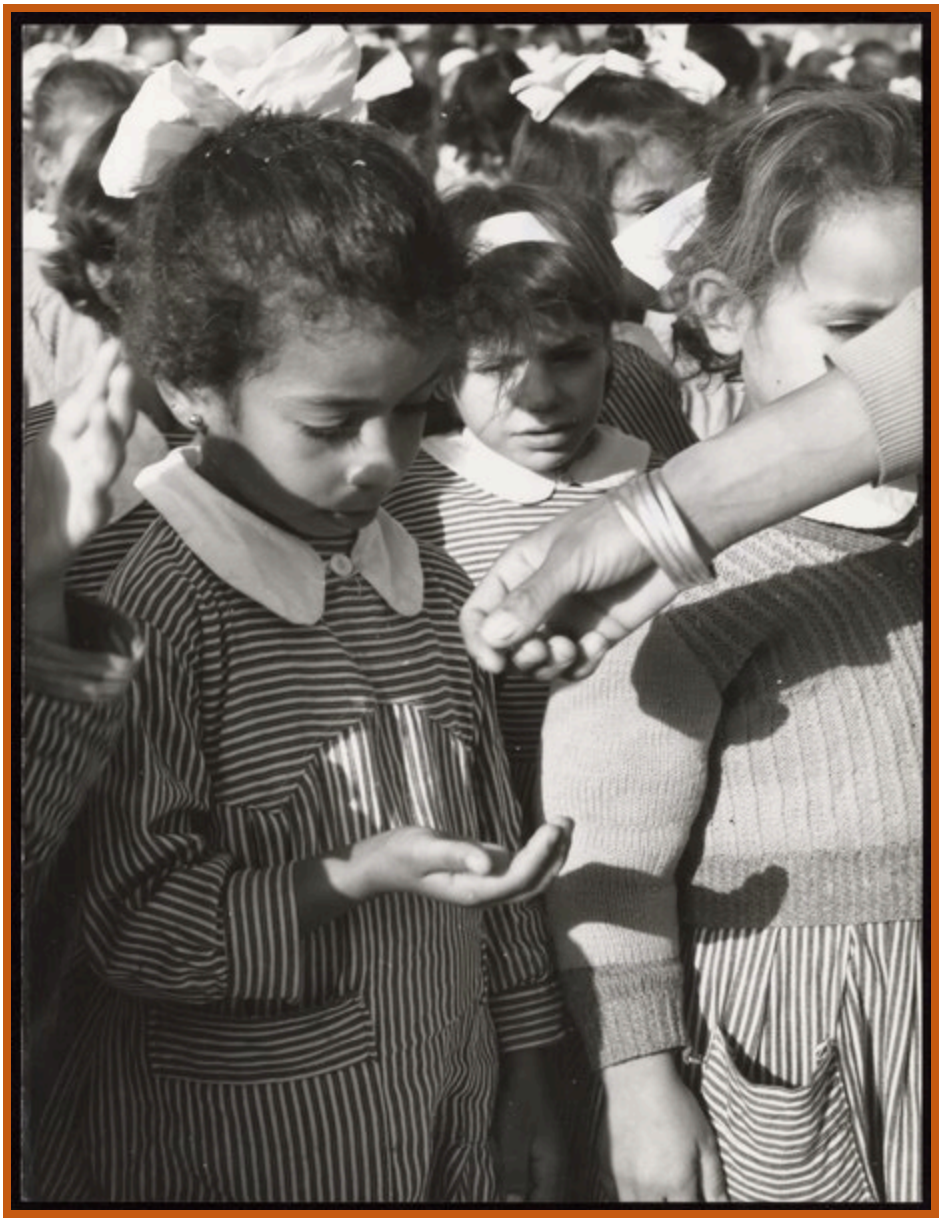


Figure 10.26: Historically, cod liver oil (a rich source of vitamin D) was given to children to prevent rickets. Image by UNESCO / Dominique Roger under CC BY-SA 3.0 IGO license.

Vitamin D is not found in very many foods naturally. Fatty fish, such as salmon, tuna, and mackerel, and fish liver oils are among the best sources. Lesser amounts of vitamin D_3 are found in egg yolks and beef liver. Mushrooms that have been exposed to UVB rays provide vitamin D_2.

In the United States, a milk fortification program was implemented in the 1930s as a public health intervention to lower the prevalence of rickets, a vitamin D deficiency in children. Other foods such as orange juice and ready to-eat cereals are now fortified with vitamin D.[59]

Another source of vitamin D is the skin synthesis of vitamin D_3 when exposed to the sun's UVB rays. Anything that reduces your exposure to the sun's UVB rays decreases the amount of vitamin D_3 your skin synthesizes. The season of the year, latitude, altitude, cloud cover, time of day, and air pollution can affect the amount of UVB rays that reach the earth. Other factors that decrease vitamin D_3 synthesis include wearing sunscreen and darkly pigmented skin. [56, 59]

Vitamin D Recommendations

The Dietary Reference Intake recommendations for vitamin D is given in micrograms. Similar to vitamin A, older Food Supplement labels list vitamin D amounts in International Units (IU). The biological value of 40 IU of vitamin D is equal to 1 microgram.[57]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	**10 mcg**	**10 mcg**		
7-12 months	**10 mcg**	**10 mcg**		
1-3 years	**15 mcg**	**15 mcg**		
4-8 years	**15 mcg**	**15 mcg**		
9-13 years	**15 mcg**	**15 mcg**		
14-18 years	**15 mcg**	**15 mcg**	**15 mcg**	**15 mcg**
19-70 years	**15 mcg**	**15 mcg**	**15 mcg**	**15 mcg**
71+ years	**20 mcg**	**20 mcg**		

Table 10.13: Vitamin D DRI recommended intakes[13]

*Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations.

Vitamin D Deficiency and Toxicity



Figure 10.27: Rickets, a severe vitamin D deficiency in children, causes malformation of the bones. Image by Wellcome Collection gallery (2018-04-01) under CC BY 4.0 license.

A deficiency of vitamin D in children causes nutritional rickets, a bone disease. Rickets is characterized by soft, weak, deformed bones that are exceptionally susceptible to fracture.

In adults, vitamin D deficiency causes osteomalacia, which is characterized by poor bone mineralization. Osteomalacia differs from osteoporosis in that bone is still present but is not adequately mineralized with calcium. Osteoporosis has a loss of bone structure. Osteomalacia has the same symptoms and consequences as osteoporosis and often coexists with osteoporosis. Vitamin D deficiency is common, especially in the elderly population, dark-skinned populations, and in the many people who live in the northern latitudes where sunlight exposure is decreased during the long winter season.

Excessive vitamin D intake from supplements can cause adverse effects. Vitamin D toxicity has been observed in adults consuming over 1250 micrograms (50,000 IU) a day and can cause elevated levels of calcium in the blood and lead to calcium deposits in the kidneys and other organs of the body. Research suggests a vitamin D toxicity is unlikely in healthy people consuming under 250 micrograms (10,000 IU) a day.[58] An adult UL of 100 micrograms has been established. [56]

Excessive exposure to the sun will not cause a vitamin D toxicity. The skin production of vitamin D_3 is a regulated process, so when the body has adequate vitamin D the synthesis of vitamin D stops.

Vitamin E

Naturally occurring vitamin E has eight vitamers, four of which are tocopherols and four are tocotrienols. All the forms of vitamin E have varying levels of antioxidant properties; however, alpha-tocopherol is the only one that is recognized to meet human requirements.[60]

Unlike most other nutrients, vitamin E does not have a specific role in metabolism. The main function of alpha-tocopherol in the body is to act as a fat-soluble antioxidant and protect cell membranes against lipid destruction caused by free radicals.[60] 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.[61]

Other functions of vitamin E include regulation of gene expression, immune function, and cell signaling.[60] 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.

Vitamin E Sources

The best food sources of vitamin E are oils and nuts. Wheat germ oil, sunflower oil, almonds, and canola oil are among the best sources for alpha-tocopherol.

Vitamin E Recommendations

The Dietary Reference Intake recommendations for vitamin E is alpha-tocopherol and is given in milligrams. Like vitamin A and D, older Food Supplement labels list vitamin E amounts in International Units (IU). The biological value of 1 IU of the natural form of alpha-tocopherol is equal to 0.67 milligrams of alpha-tocopherol. The biological value of 1 IU of synthetic alphatocopherol (often found in supplements) is 0.45 milligrams of alpha-tocopherol. [62]



Figure 10.28: Examples of foods containing vitamin E. This includes healthy oils, nuts and seeds, and some vegetable sources. Created by AL.

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	4 mg*	4 mg*		
7-12 months	5 mg*	5 mg*		
1-3 years	**6 mg**	**6 mg**		
4-8 years	**7 mg**	**7 mg**		
9-13 years	**15 mg**	**15 mg**		
14-18 years	**15 mg**	**15 mg**	**15 mg**	**19 mg**
19-70 years	**15 mg**	**15 mg**	**15 mg**	**19 mg**
71+ years	**15 mg**	**15 mg**		

*Indicates Adequate Intake recommendation. Bolded items indicate RDA recommendations

Table 10.14: Vitamin E (alpha-tocopherol) DRI recommended intakes[13]

Vitamin E Deficiency and Toxicity

A severe deficiency of vitamin E with clinical symptoms is rare in humans. Groups at risk for deficiency include premature infants with a very low birth weight and individuals with fat malabsorption. Clinical symptoms include hemolytic anemia and degeneration of nerve cells.[63]

No adverse effects have been found from consuming vitamin E in food. However, there have been reports of impaired blood coagulation when high doses of alpha-tocopherol supplements are taken. High doses of vitamin E can antagonize vitamin K-dependent clotting factors.[62] An adult UL of 1,000 mg of vitamin E from supplements has been established. [60]

Vitamin K

During the 1920s, Danish researcher H. Dam discovered a vitamin that was necessary for blood clotting and named it vitamin K after the Danish word koagulation which means coagulation.[64] Vitamin K vitamers can be categorized in the groups phylloquinone (vitamin K1) which are found in plants, and menaquinone (vitamin K2) most of which are synthesized by bacteria in the large intestine although some is found in fermented foods.[65]

Vitamin K functions as a coenzyme and has an essential role in blood coagulation. Without vitamin K, blood would not clot. Vitamin K is also required for maintaining bone health. It modifies proteins involved in the bone remodeling process. All the functions of the vitamin K-dependent proteins in bone tissue are not well understood and are under intense study. Some studies do show that people who have diets low in vitamin K also have an increased risk of bone fractures.

Vitamin K Sources

Vitamin K is present in many foods. It is found in highest concentrations in green vegetables such as broccoli, cabbage, kale, parsley, spinach, and lettuce. Additionally, vitamin K can be synthesized via bacteria in the large intestine. The exact amount of vitamin K synthesized by bacteria that is absorbed in the lower intestine is not known, it is believed to contribute to the vitamin K requirements but to a lesser amount than what was originally thought.[66]

Vitamin K Recommendations

An RDA could not be determined for vitamin K, and so the vitamin K recommendations for all age groups are Adequate Intakes and based on dietary reports of healthy population groups.[67]

Age	Male	Female	Pregnancy	Lactation
Birth to 6 months	2.0 mcg*	2.0 mcg*		
7-12 months	2.5 mcg*	2.5 mcg*		
1-3 years	30 mcg	30 mcg		
4-8 years	55 mcg*	55 mcg*		
9-13 years	60 mcg*	60 mcg*		
14-18 years	75 mcg*	75 mcg*	75 mcg*	75 mcg*
19-70 years	120 mcg*	90 mcg*	90 mcg*	90 mcg*
71+ years	120 mcg*	90 mcg*		

Table 10.15. Vitamin K DRI Recommended Intakes[13]

*Indicates Adequate Intake recommendation.

Vitamin K Deficiency and Toxicity

Vitamin K deficiencies are not common in healthy individuals. A deficiency may occur in adults with malabsorption disorders and results in poor blood clotting, hemorrhage, and low bone mineralization.

Newborns have low vitamin K stores because vitamin K transport across the placenta is poor. The American Academy of Pediatrics recommends newborns receive a single intramuscular dose of vitamin K. [26] This practice has greatly decreased vitamin K-dependent bleeding disorders in babies.

Vitamin K can interact with anticoagulants such as warfarin (Coumadin). People who take these medications need to maintain a consistent intake of vitamin K from food and supplements. Vitamin K is still essential to consume, but sudden changes with intakes may increase or decrease the anticoagulant effect.[68]

A UL for vitamin K has not been determined because no adverse effects have been associated with vitamin K consumption from food or supplements.[67]

Key Takeaways

- *Vitamin A has two forms: preformed vitamin A from animal products, which can be toxic in high doses, and provitamin A from plants (like carrots), which the body converts as needed and is not toxic. Its deficiency can lead to night blindness and even permanent blindness.*
- *Vitamin D is unique because the body can synthesize it from sun exposure. It's essential for regulating calcium absorption and bone health, and its deficiency can cause rickets in children and osteomalacia in adults.*
- *Vitamin E primarily functions as a fat-soluble antioxidant that protects cell membranes from damage caused by free radicals. High doses from supplements can interfere with blood clotting.*
- *Vitamin K is a critical coenzyme for blood clotting. Although deficiencies are rare in healthy adults, a single dose is given to newborns to prevent bleeding disorders.*
- *Both Vitamin A and Vitamin D are well-known for their potential for toxicity if consumed in extremely high amounts through supplements, which is why it's important to be mindful of intake.*

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5

Chapter 5: Minerals

5.1. Introduction to Minerals

5.2. Major Minerals

5.3. Trace Minerals

5.1

Introduction to Minerals

9.1 Introduction to Minerals

The book of Genesis teaches us that our physical bodies were formed from the dust of the earth.[1] The details of the process God used to create the bodies of our first parents' has not been revealed, but today's science can certainly verify that the elements found in the earth are consistent with elements that make up a human body. The periodic table is a collection of the known elements. Regular dietary intake of many of the elements is necessary to sustain life. Carbohydrate, protein, fat, water and vitamins are essential nutrients that are composed of combinations of different elements; mostly carbon, hydrogen, oxygen, nitrogen, and some sulfur (see highlighted elements in Figure 1). These elements are organized into essential organic (carbon-containing) compounds by plants and animals that humans then eat to sustain life. In addition, a number of other elements in the periodic table are also dietary essentials but perform their function as inorganic elements(do not contain carbon.) These are referred to as the essential minerals and must be consumed in the diet for health to be sustained.



Figure 9.1: Creation of the earth. Image by Luminas_Art via pixabay.

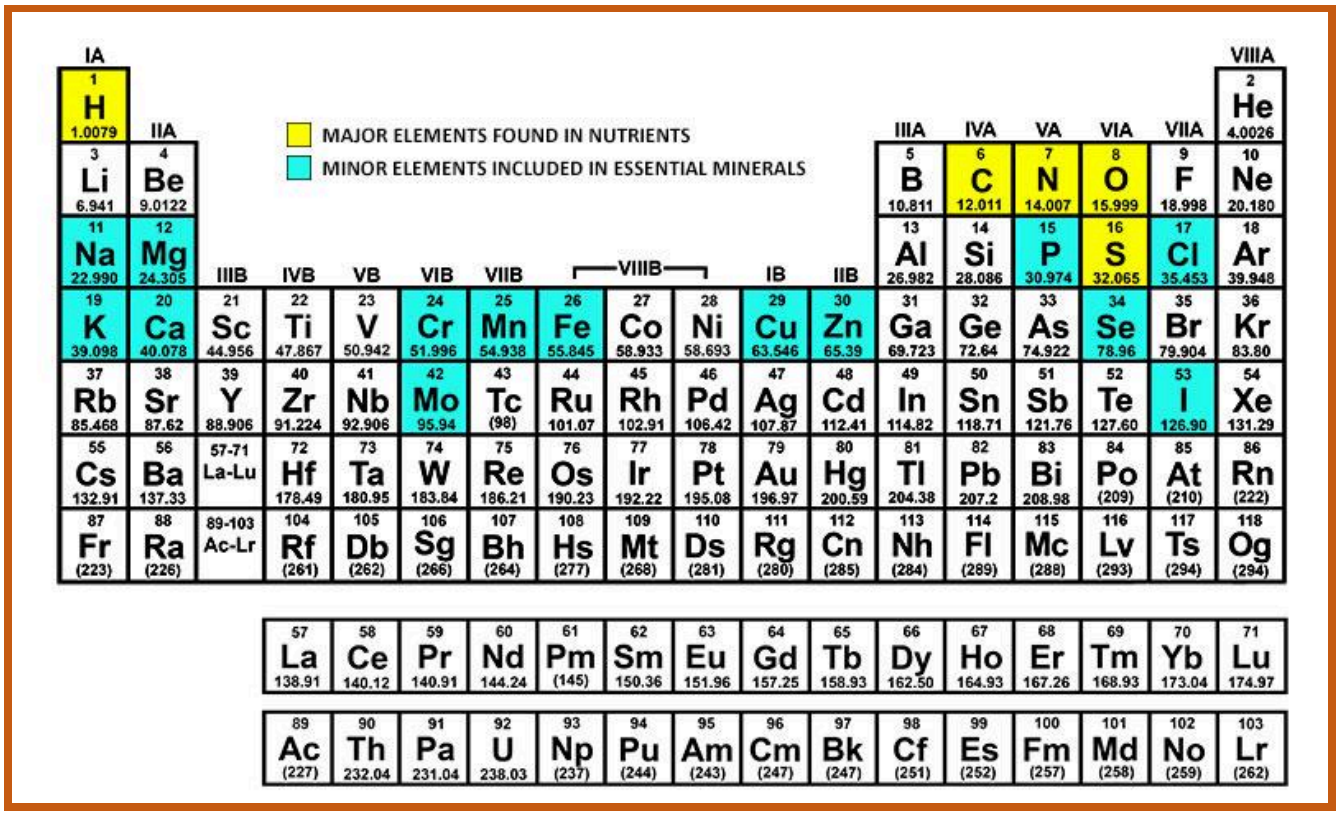


Figure 9.2: Periodic table of elements, our bodies are made from these elements, and some are required in our diet for good health

The essential minerals can then be further subdivided into two groups: the major minerals and trace minerals. Major minerals are needed by adults in quantities greater than 100 mg/day. Minerals needed in amounts of 100 mg/day or less are grouped into the trace and ultra-trace mineral categories. For the ease of discussion, the trace and ultra-trace minerals will be grouped into one category and referred to as trace minerals (see Figure 2).

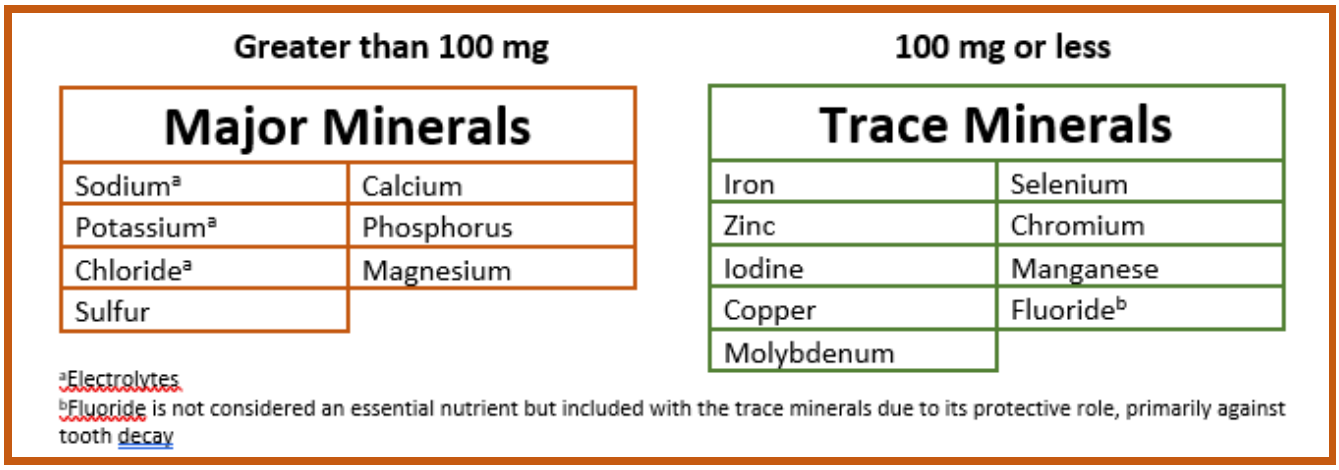


Figure 9.3: Major and trace minerals

By studying the highlighted minerals on the periodic table, it is apparent that only a fraction of the elements has been established as essential. It is interesting to note that the discussion on the essentiality of a number of the remaining minerals is still open. For example, boron, vanadium, silicon, and arsenic are among those minerals that are not considered essential currently but are under discussion as possible essential nutrients. The inclusion of arsenic may be curious to some, due to its

high toxicity even in very small quantities. But the fact that many of the minerals, if taken in excess, can be dangerous makes the consideration of arsenic in extremely low doses more understandable.

Functions of Minerals

Because of their physical properties, minerals are often recognized for their structural role. For example, minerals are a primary component of bones and teeth. Minerals also play a substantial regulatory role. For example, they are key cofactors in many enzymatic reactions affecting key events such as DNA transcription, metabolism and muscle contraction. A cofactor is a metallic substance that is necessary for an enzyme to function properly. The minerals sodium, potassium, and chlorine have a unique role in fluid balance and nerve conduction. Because of their close association with water, they were discussed in the fluid chapter.

Minerals in our food supply

Where we get our food, how the food is processed, and how we prepare our food can alter the mineral content, particularly in plant-based foods. For example, in many areas of the world iodine has been leached from the soil. Plants grown in these areas will be low in iodine. Plants grown in iodine-rich soils versus iodine-poor soils may have 100 times more iodine content.[2] The mineral content of animal-based foods are often higher than plant-based foods because the animal eats the plants and concentrates the minerals from the plants to the desired level.

The processing of food can decrease or increase the mineral content of foods. For example, when grains such as wheat and rice are processed, often the bran and germ are removed, which contain a substantial amount of the important minerals found in these grains. In the United States, it is required by law that iron is added back in. Unfortunately, other minerals originally found in the grains such as magnesium, zinc, and copper are not required to be added back in (see Figure 3). In contrast, sodium levels are often increased. This is not a desired change for most people.

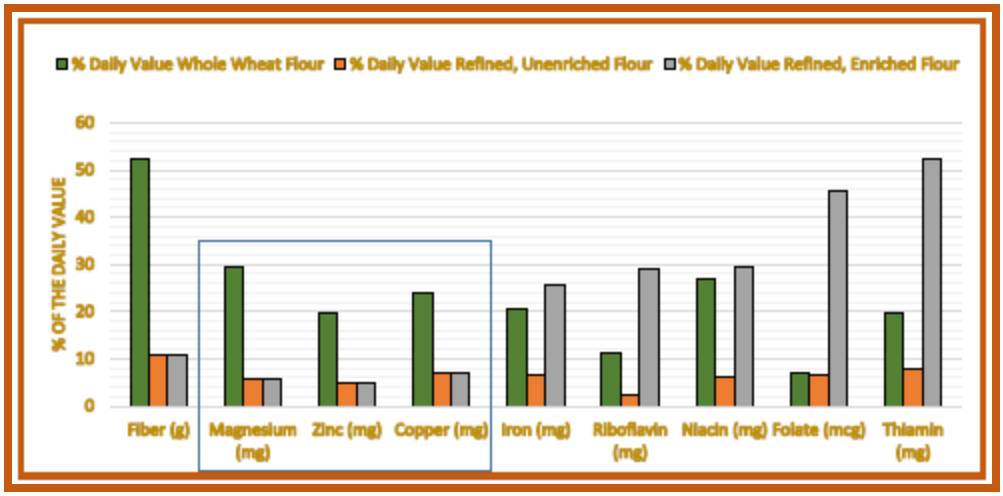


Table 9.1: Removal of magnesium, zinc and copper during processing

Minerals may be intentionally added to some foods for specific health benefits. For example, iodine is added to salt. While these carefully selected additions to our food have proven helpful, the random fortification of minerals and vitamins to processed food products has become so common that the wisdom of this continued pattern can be questionable.

Minerals can also sneak into our food supply unintentionally. For example, cooking with cast iron cookware can increase the iron content of the food, and iodine has found its way into our milk supply due to its use as a sterilization agent in the milking process. Neither of these additions are harmful, and in some cases there could be a health benefit. However, the unintentional addition of potentially harmful levels of minerals may be a concern.

Bioavailability

Food composition tables list the amount of the various minerals found in many foods. What is not clear from these tables is the actual ability of the body to absorb and use the minerals in a particular food. The term **bioavailability** is used to describe this principle. Generally, it is other substances that are in the food that affect the bioavailability of minerals. Minerals found in animal products generally have a higher bioavailability compared to minerals found in plant based foods. The presence of phytates, oxalates, and polyphenols such as tannins in plant-based foods all negatively affect the bioavailability of certain minerals. For example, oxalates (found in some leafy greens vegetables like spinach) negatively impact the absorption of calcium. Phytates (found in whole grains) negatively impact the absorption of zinc. Some might wonder if this is a justification to eat refined grains more often, but despite the decreased bioavailability of zinc in whole grains, the increased levels of zinc in the whole versus refined grains more than makes up for the difference in bioavailability.[3]

Minerals of similar charge can compete for absorption; for example, calcium and iron are both positively charged minerals and compete for absorption. Under normal dietary circumstances, the effect is small, but if large amounts of these minerals are taken as supplements the concern increases. In contrast, the effect of substances on the bioavailability of minerals is not always negative; the presence of vitamin C with certain forms of iron can increase the availability of iron. The nutritional need of an individual can also positively impact the bioavailability of some nutrients. For example, during pregnancy the bioavailability of several nutrients increases to meet the increased need of the mother and developing fetus.

Mineral Bioavailability

Lower Bioavailability	Higher Bioavailability
Phytates	Generally animal foods
Oxalates	Stage in lifecycle (example pregnancy and calcium)
Polyphenols (Tannins)	Vitamin C and non-heme iron
Mineral Supplements with same charge	Vitamin D and Calcium

Table 9.2: Factors influencing mineral bioavailability

Key Takeaways

- *Minerals are inorganic elements essential for life that are not composed of carbon. They are divided into two categories: major minerals (needed in amounts greater than 100 mg/day) and trace minerals (needed in amounts less than 100 mg/day).*
- *Minerals have two main functions in the body: structural (as a primary component of bones and teeth) and regulatory (as cofactors that help enzymes function properly).*
- *The mineral content of food can be affected by the soil it's grown in and by processing. For example, processing grains removes beneficial minerals like magnesium and zinc, while often increasing less-desirable minerals like sodium.*
- *Bioavailability, or the body's ability to absorb and use minerals, varies widely. Minerals from animal products are generally more bioavailable than those from plant foods due to substances like phytates and oxalates in plants that inhibit absorption.*
- *Mineral bioavailability can be influenced by other nutrients (e.g., Vitamin C and iron), competition between minerals with similar charges, and the body's specific nutritional needs (e.g., during pregnancy).*

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5.2

Major Minerals

9.2 Major Minerals

Calcium

Calcium makes up 1-2% of an adult human's body weight. Greater than 99% of total body calcium plays a structural role and is found in the bones and teeth. The other 1% is found in body fluids. Despite the magnitude of difference in calcium content between the two compartments, the calcium found in body fluids is no less important. Because of calcium's complex role, overall intake and regulation of calcium levels are important not only for structural reasons but for the maintenance of a wide variety of other critical functions.

Functions of Calcium

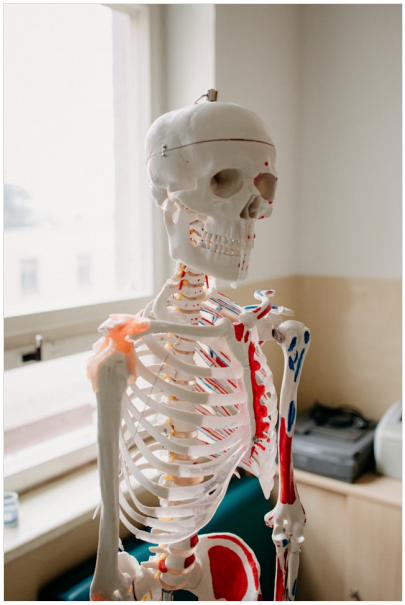


Figure 9.4: The skeleton: the calcium in the bone serves as a calcium reserve. Image by Trnava University on Unsplash.

The most familiar function of calcium is to provide structure for the human body. As an integral part of bone, it provides a strong framework that determines body shape and allows a person to move. The calcium in bones is actually part of a mineral complex called hydroxyapatite.

It may be surprising to learn that calcium has several other functions besides helping to make bones strong. In fact, calcium levels in body fluids play a critical role in blood clotting, nerve conduction, muscle contraction, and blood pressure regulation. These calcium functions are critical to life. Providing calcium for functions other than structure is so critical, that the body will take calcium from bones when there is not enough calcium in the diet to maintain the necessary calcium levels in body fluids. Long-term low calcium intake will result in a continual slow release of calcium from bone and increases risk for osteoporosis. It may take several years before the impact on bone density is realized. Eating calcium rich foods over a lifetime is an important part of preventing the geriatric disease of osteoporosis.

Regulation of calcium

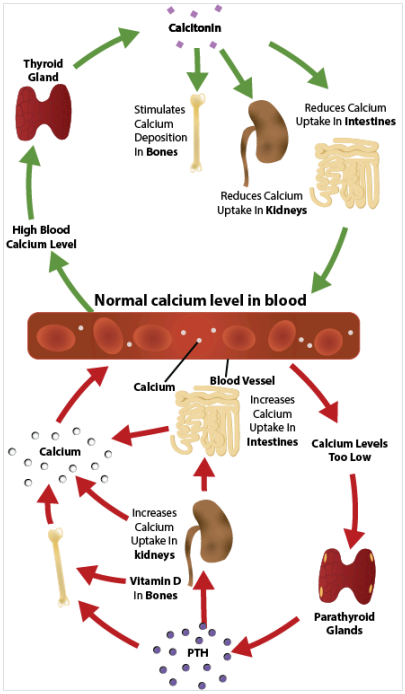


Figure 9.5: Regulation of blood calcium levels. Created by AP.

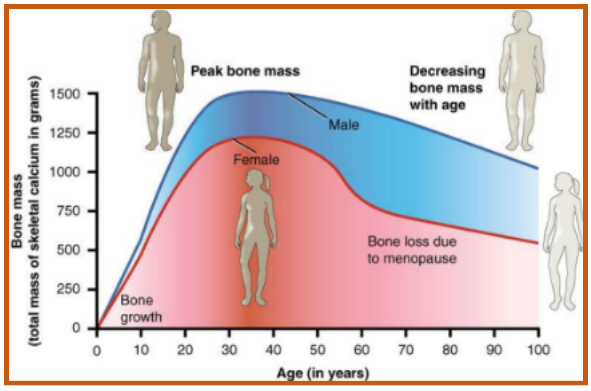


Figure 9.6: Bone mass over time. Image by OpenStax College under CC BY 3.0 license.

Calcium Recommendations and Deficiency

Calcium recommendations change over the lifespan (see Table 2). During the adolescent and teen years, calcium recommendations are higher to accommodate bone growth and development. Recommendations drop to 1000 mg/day in adulthood. Calcium absorption drops with age and women have a greater bone loss after menopause. Consequently, recommendations increase to 1200 mg/day for females over the age of 50 and for men over the age of 70. Interestingly the calcium recommendations during pregnancy and lactation are the same for non-pregnant and lactating women of the same age. This is because during pregnancy dietary absorption of calcium doubles. This increased absorption ensures adequate calcium availability for the growing baby and the increased needs of the pregnant woman.

Age Range	RDA	UL
9-18 (male/female)	1300 mg/day	3000 mg/day
19-50 (male/female)	1000 mg/day	2500 mg/day
51-70 (males)	1000 mg/day	2000 mg/day
51-70 (females)	1200 mg/day	2000 mg/day
>70 (male/female)	1200 mg/day	2500 mg/day

Age Range	RDA	UL
14-18 (pregnant/lactating)	1300 mg/day	3000 mg/day
19-50 (pregnant/lactating)	1000 mg/day	2500 mg/day

Table 9.3: Recommended calcium intake levels[5]

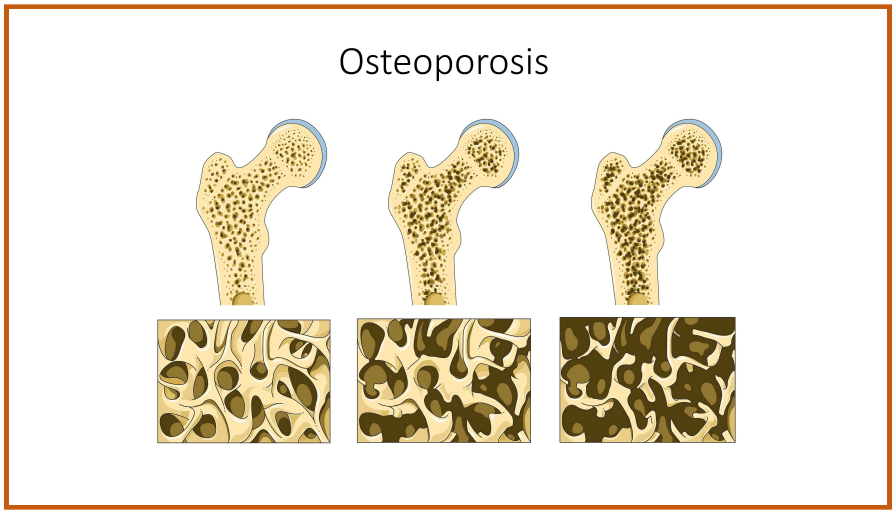


Figure 9.7: Normal bone, progressing to osteoporotic bone. Image by Laboratoires Servier under CC BY-SA 3.0 license.

Because of the dynamic nature of bone and the vast amount of available calcium in the bone, the key functions of calcium (nerve conduction, muscle contraction etc.) are typically maintained regardless of calcium intake. It is usually not until later in life that a deficiency of calcium in the bone manifests itself as **osteoporosis**. Osteoporosis (porous bone) is a disease of low bone mass leading to an increased risk of fractures. [6] In the United States, it is estimated that 53 million people either have osteoporosis or are at high risk secondary to low bone mass. [6] It is a serious and debilitating disease.

Low calcium intake is certainly a risk factor for osteoporosis, but there are other factors that affect bone density as well. Other nutrients such as vitamin D, protein, phosphorus, magnesium and vitamin K are also important in bone development and can potentially impact bone density. Women are at a much higher risk for osteoporosis than men for several reasons. On average, women have a lower peak bone mass than men. As a result, after age 40 when bone mass starts to decline, women have less mass to draw upon. Hormones also have a significant role in the maintenance of bone mass in women. When estrogen levels decrease at menopause, bone loss accelerates in women increasing the likelihood of the development of low bone mass. Osteoporosis typically occurs in old age, but under certain circumstances it can also develop at a young age. For example, female athletes that struggle with amenorrhea (lack of menstruation) secondary to inadequate caloric intake, can become osteoporotic at an early age due to changes in estrogen levels. (See Figure 6 for an example of osteoporotic bone). Not surprisingly, as the



Figure 9.8: Foods high in calcium. Created by AP.

density of bone decreases the risk of fractures increases. For older individuals, a fracture associated with osteoporotic bones is difficult to heal and affects not only quality of life but also life expectancy. [7]

Dietary sources of calcium and prevention of osteoporosis

Dairy products are naturally one of the densest sources of dietary calcium. Fortunately for the many people who are not able to eat dairy products because of lactose intolerance or allergies, there are many other calcium-rich foods that can be eaten (see Table 3).

Food (dairy)	Calcium (mg)	Food (non-dairy)	Calcium (mg)
Milk, 1% (8 ounces)	305 mg	Sardine, canned with bones (3 ounces)	325
Yogurt, plain (8 ounces)	209 mg	Collard Greens (1 cup cooked)	268
Cheese, Cheddar (1 ounce)	200 mg	Tofu, firm (1/2 cup)	253
		Almonds (1/2 cup whole)	192
		Turnip greens (1 cup cooked)	197
		Kale (1 cup cooked)	94
		Tahini (sesame seed paste, 1 tbsp)	63
		Broccoli (1 cup cooked)	62

Table 9.4: Sources of calcium

When vitamin D levels are low, the absorption of calcium from food and supplements decreases from 25-33 percent to less than 10-15 percent.[32] The bioavailability can decrease depending on other food components that may be present during digestion and the amount of calcium taken in at a given time. About 25-30% of dietary calcium is typically absorbed.[8] Many green vegetables have a significantly higher absorption rate (50-70%), but will vary drastically depending on the presence or absence of binders such as oxalates. For example, spinach contains calcium, but only about 5% of the calcium can be absorbed because of the oxalate content of spinach.[9] If calcium is taken as a supplement, it is recommended to take a dose of 500 milligrams or less because the calcium absorption decreases when higher amounts are taken.

Some of the risk factors associated with osteoporosis such as age, gender, genetics, and nationality are not controllable, but other factors are. A healthy balanced diet that supplies an adequate amount of calories as well as all the essential nutrients, particularly those involved in bone development, is important. Regular weight-bearing exercise will increase bone density. For example, sports such as volleyball, soccer, basketball, and racquetball will build bone density better than sports like swimming or cycling. Other lifestyle factors such as smoking and alcohol consumption can negatively impact bone mass. These prevention strategies work in two ways. If followed early in life they help peak bone mass to be achieved, and if continued throughout life, they can also minimize the rate of bone loss that inevitably occurs after age 40. The most potent preventive action to decrease the risk of osteoporosis is to establish healthy practices during childhood and adolescence. 4 Unfortunately, some adolescents struggle making food choices that allow them to get adequate calcium and other important minerals necessary for bone health. A well-rounded diet adequate in vegetables and dairy products is key to meeting these goals.

Extremely high intakes of calcium in a short amount of time, or chronic exposure to high calcium intake, can be harmful. This can lead to calcium deposits in soft tissues such as the kidney and heart, increase the risk for kidney stones and possibly increase the risk for cardiovascular disease. The UL for calcium has been set at 2500 mg/day.[5]

Phosphorus

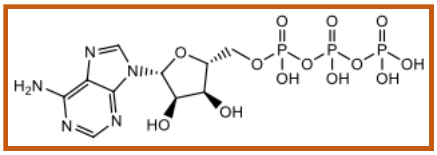


Figure 9.9: Structure of adenosine triphosphate. Image by Colin Wong under CC BY-SA 4.0 license with edits.

Phosphorus is the second most abundant mineral in the human body. Eighty-five percent of it is housed in the skeleton. In addition to serving as a primary mineral in the skeleton, phosphorus in the form of phosphate is a component of RNA and DNA, the energy-storing molecule ATP (adenosine triphosphate), and phospholipids. Because phosphorus is present with calcium in mineralized bone, it is also regulated by the parathyroid hormone, calcitonin, and calcitriol (the active form of vitamin D.)

Food Sources and Recommendations for Phosphorus

In comparison to calcium, most Americans are not at risk of having a phosphate deficiency. Phosphate is present in many popular foods including meat, fish, dairy products, processed foods, and beverages. Phosphate is added to many foods because it acts as an emulsifying agent, prevents clumping, improves texture and taste, and extends shelf-life. The average intake of phosphorus in US adults ranges between 1,000 and 1,500 milligrams per day, well above the RDA of 700 milligrams

per day. The UL set for phosphorus is 4,000 milligrams per day for adults and 3,000 milligrams per day for people over age seventy.[5]

Magnesium

Approximately 60 percent of magnesium in the human body is stored in the skeleton, making up about 1 percent of mineralized bone tissue. Magnesium is not an integral part of the hydroxyapatite crystal, but it does reside on the surface of the crystal and helps maximize bone structure. Studies link magnesium deficiency with an increased risk for osteoporosis.[10,11] It may be connected with osteoporosis due to its direct structural role in bone, but magnesium is also associated with the activity of several hormones linked to bone remodeling such as vitamin D. A magnesium-deficient diet is associated with decreased levels of parathyroid hormone and decreased activation of vitamin D, which may lead to an impairment of bone remodeling.

In addition to participating in bone maintenance, magnesium has a wide variety of other functions in the body. In every reaction involving the cellular energy molecule (ATP), magnesium is required. More than three hundred enzymatic reactions require magnesium. Magnesium plays a role in the synthesis of DNA and RNA, carbohydrates, and lipids, and is essential for nerve conduction and muscle contraction. Another health benefit of magnesium is that it may decrease blood pressure.

Food Sources and Recommendations for Magnesium

Figure 9.10 :Foods high in magnesium. Created by AP.

Magnesium is part of the green pigment chlorophyll, which is vital for photosynthesis in plants; therefore, green leafy vegetables are a good dietary source for magnesium. Good sources of magnesium also include legumes, nuts, seeds, and whole grains. Hard water also contains some magnesium. Drinking two liters of hard water can provide about 52 milligrams of magnesium. Most people in America do not fulfill the RDA for magnesium in their diets. Typically, Western diets have a low intake of fish, green leafy vegetables, whole grains, and nuts, making it difficult to achieve the recommendations.

The RDAs for magnesium for adults between ages nineteen and thirty are 400 milligrams per day for males and 310 milligrams per day for females. For adults above age thirty, the RDA increases slightly to 420 milligrams per day for males and 320 milligrams for females.[5]

Key Takeaways

- *Calcium provides the structural framework for the body (over 99% is found in bones and teeth), but also has critical functions in nerve and muscle contractions.*
- *When dietary calcium intake is too low, the body pulls calcium from bones to maintain blood levels, which can lead to the bone-weakening disease osteoporosis over time.*
- *Phosphorus is the second most abundant mineral in the body, primarily located in the skeleton, and is a key component of DNA, RNA, and the energy molecule ATP.*
- *Magnesium is involved in over 300 enzymatic reactions, plays a crucial role in bone health, nerve conduction, and muscle contraction, and may help lower blood pressure.*
- *In the US, most people consume enough phosphorus due to its widespread use in processed foods, but many do not get the recommended amount of magnesium.*

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5.3

Trace Minerals

9.3 Trace Minerals

Iron

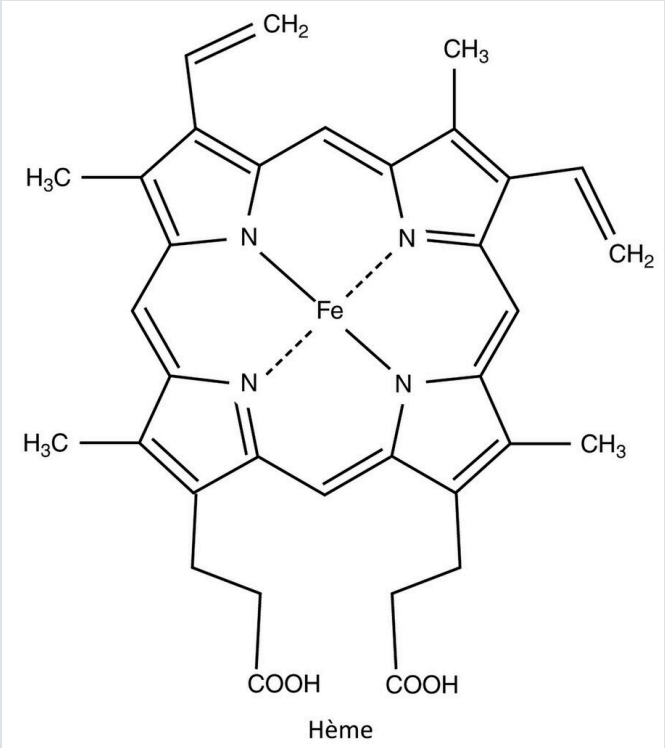


Figure 9.11: Structure of heme iron. Image by Rice University under CC BY 4.0 license with edits.

Iron (Fe) is probably one of the most recognized minerals of all the essential minerals. Many people have experienced the fatigue that can be associated with low iron levels and understand its role in the oxygen delivery. Less well understood are the

best dietary strategies to ensure adequate but not excessive iron intake, and the diverse role of iron in the body.

Functions

Iron is a key participator in oxygen delivery. Red blood cells contain the oxygen-carrier protein **hemoglobin**. It is composed of four globular polypeptides (proteins), each containing a nonprotein complex called **heme** (see Figure 7). Heme is a ring-like structure containing carbon, hydrogen, and oxygen. Iron is found in the center of each heme. When all these components are present, hemoglobin is an efficient carrier of oxygen (see Figure 8). In the muscle, a similar structure used to transport oxygen is called **myoglobin**. The majority of the body's iron (approximately 70%) is found in the red blood cells of hemoglobin and myoglobin.[31] In addition, many of the proteins of the electron-transport chain contain iron. It is vital for the synthesis of ATP. Iron is also a cofactor for hundreds of enzymes participating in events such as DNA synthesis and detoxification reactions in the liver.

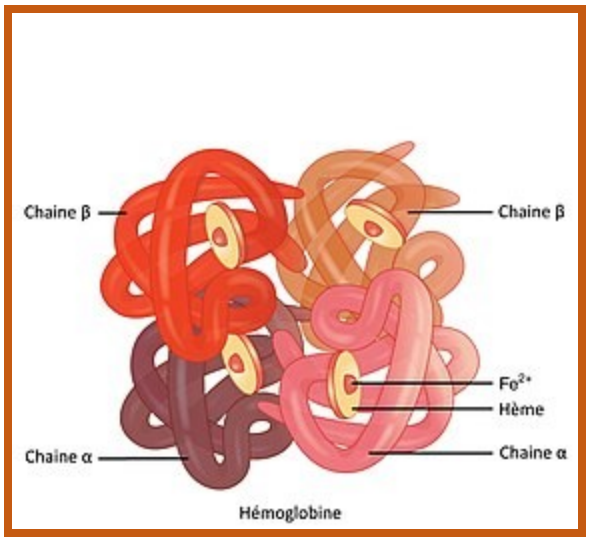


Figure 9.12: Structure of hemoglobin. Image by Rice University under CC BY 4.0 license with edits.

Food sources

Dietary iron is found in two basic forms, **heme** and **non-heme**. When eating animal products such as meat, fish, and poultry, much of the iron that is ingested is still a part of a hemoglobin or myoglobin complex. The digestive process breaks down the polypeptide chains and releases the heme ring containing the iron. During digestion the heme ring stays intact and the iron is still secured in the middle. Fifty to sixty percent of the iron found in animal products is heme iron, the remaining iron is elemental or non-heme iron. [12] Animal products contain both forms of iron, but plants provide only non-heme iron. Dietary sources of heme and non-heme iron are listed in Table 4.

Animal Sources-Containing Heme and Non-Heme Iron	Iron (mg)	Plant Sources - Containing Non-Heme Iron	Iron (mg)
Oysters (3 oz)	5.7	Fortified Cereal (25% of DV)	4.5
Liver (3 oz)	4.1	Spinach (1/2 cup cooked)	3.2
Beef, round (3 oz)	2.3	Pumpkin seeds (1/4 cup)	2.4
Turkey leg (3 oz)	1.9	Black beans (1/2 cup)	1.8

Animal Sources-Containing Heme and Non-Heme Iron	Iron (mg)	Plant Sources - Containing Non-Heme Iron	Iron (mg)
Turkey breast (3 oz)	1.1	Dried Apricots (1/2 cup)	1.7
		Whole wheat bread (1 slice)	0.9
		Enriched bread (1 slice)	0.9
		Broccoli (1/2 cup cooked)	0.5

Table 9.5: Sources of iron

Absorption, transport and storage

The bioavailability of iron from food is dependent on a number of factors. Generally, iron is not a well absorbed mineral. In a mixed meal, iron absorption is estimated to be 14-18% and as low as 5% in vegetarian meals.[13] When iron is bound within heme, it is better absorbed than in the



Figure 9.13: Foods high in iron. Image created by AP.

elemental form (non-heme). The digestive system has transporters that specialize in the absorption of heme iron. When there is a specific need to increase body iron levels, such as in iron deficiency anemia, animal products such as liver and red meats

are often promoted by health professionals to help restore iron levels. But under normal circumstances plant products can provide good amounts of iron and are an important part of a healthy diet. It is important to be aware that the absorbability of iron from plant products can either be enhanced or diminished depending of the presence of other compounds within the same food or food eaten at the same time. Some plants contain compounds such as phytates, oxalates, and polyphenols (such as tannins) that inhibit non-heme iron absorption. For example, black tea is rich in polyphenols and known to reduce iron absorption. While black tea isn't a significant source of iron, it can inhibit iron absorption when consumed with iron-containing foods or supplements.[13] In contrast, there are other food substances that can increase the absorption of non-heme iron. Vitamin C is recognized for its ability to increase non-heme iron absorption. For example, eating an orange with an iron-fortified cereal in the morning will increase the absorption of the non-heme iron in the cereal, or chopping up green and red peppers (high in vitamin C) in a spinach salad is another demonstration of the principle. The "meat factor" is also a means to increase non-heme iron absorption. While the mechanism has remained elusive, studies have shown that including meat, fish, or poultry with a heme iron source increases non-heme iron absorption.[13] For example, adding strips of chicken to a mixed green salad would not only increase the iron content of the salad by adding the meat, but also increase the absorption of the non-heme iron in the vegetables.

Once iron is absorbed into the intestinal cells, the amount of iron that leaves the intestinal cells will depend on body iron levels. If iron levels are good, much of the iron may stay in the intestinal cells as ferritin, a storage form of iron. If the iron has not been moved into the body from the intestinal cells within 3 days (3 days is the life span of an intestinal cell), it will be removed from the body as the dead intestinal cells slough off into the intestinal tract. When body iron levels are low, more of the iron will be moved into the blood stream and transported to areas of need such

as the bone marrow. Once it has been moved into the blood from the GI tract, iron is used and recycled very efficiently. For example, when blood cells die (roughly every 120 days), the body recycles the iron back to the bone marrow where red blood cells are made. The body also stores some iron in the bone marrow, liver, spleen, and skeletal muscle as ferritin. A relatively small amount of iron is lost when skin cells die and in blood loss, such as during menstrual bleeding. The lost iron must be replaced from dietary sources.

Iron-Deficiency and Recommendation

Iron deficiency affects over 2 billion people and is the most common nutritional disorder worldwide.[14,15] It can result from poor dietary intake, poor absorption, increased need or increased losses of iron.[15] In developing countries, the most common causes are poor intake and increased losses due to parasites. In developed countries, common causes would include poor iron intake due to diet preferences (vegetarianism), heavy menstruation, or disease states that affect iron levels such as celiac disease or ulcers.[15] Those at highest risk typically include young growing children, menstruating girls and women, pregnant women, and the elderly. Iron deficiency may be first noted by a reduction in the level of stored iron (ferritin). If the deficiency progresses, iron deficiency anemia can develop. Iron deficiency anemia (a microcytic anemia) is the presence of small, pale red blood cells due to insufficient iron levels in the bone marrow for proper blood cell production. Symptoms of iron deficiency include fatigue, weakness, pale skin, dizziness and pica. A logical connection between many of the symptoms of deficiency and iron's known roles in oxygen delivery and energy metabolism is apparent. Pica is an interesting side effect often associated with iron deficiency. It is characterized by strong cravings for generally non-nutritive substances such as ice, chalk, clay and dirt.

- Fatigue
- Weakness
- Pale Skin

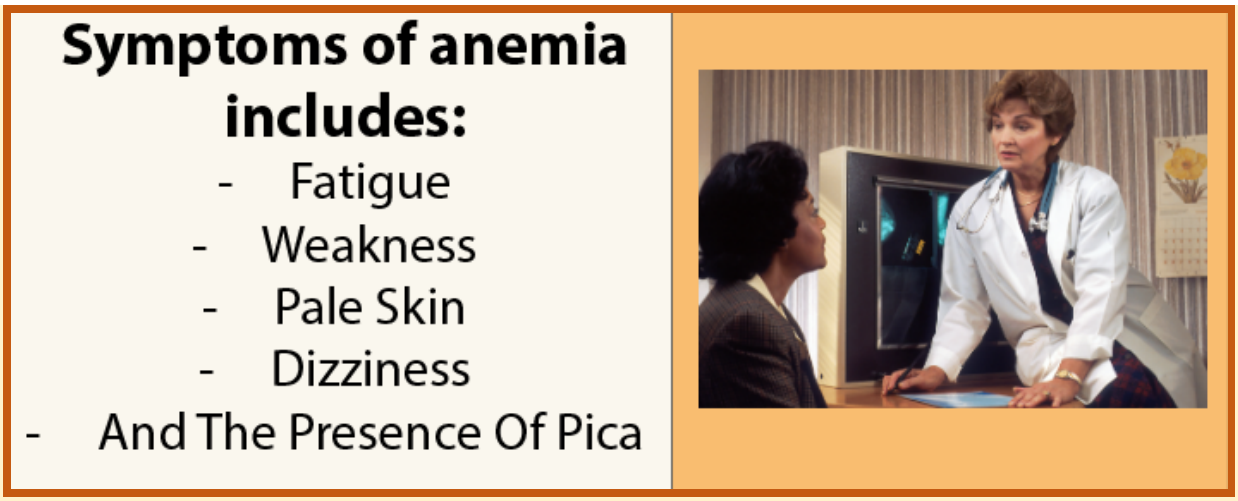


Figure 9.14: Image by National Cancer Institute on unsplash.

Symptoms of anemia include:

- Dizziness
- And the presence of pica

Iron-deficiency anemia is diagnosed from characteristic signs and symptoms and confirmed with simple blood tests that count red blood cells and determine hemoglobin and iron content in blood. Iron-deficiency anemia is most often treated with iron supplements and increasing the consumption of foods that are higher in available iron. Iron supplements may have some adverse side effects including nausea, constipation, diarrhea, vomiting, and abdominal pain. Reducing the dose at first and then gradually increasing to the full dose often minimizes the side effects of iron supplements. Avoiding foods and beverages high in phytates and other binders and eating foods that increase iron absorption (such as those high in vitamin C), are important dietary strategies for people who have iron-deficiency anemia. Recommended iron intakes are listed in Table 5.

Age Range	RDA	UL
9-13 (male/female)	8 mg/day	40 mg/day
14-18 (male)	11 mg/day	45 mg/day
14-18 (female)	15 mg/day	45 mg/day
Older than 19 (male)	8 mg/day	45 mg/day
19-50 (female)	18 mg/day	45 mg/day
Older than 50	8 mg/day	45 mg/day
Pregnant women - all ages	27 mg/day	45 mg/day

Age Range	RDA	UL
19-50 (Lactating)	9 mg/day	45 mg/day

Table 9.6: Recommend iron intake levels5

Iron Toxicity



Figure 9.15:Iron supplements. Image by Loren Garcia Batista on Pexels.

The body excretes little iron and therefore there is potential for accumulation of unhealthy amounts in tissues and organs. The body's mechanism to control iron levels in the body is to decrease iron absorption when the iron stores are full. However, iron toxicity can occur when large doses of iron are taken. Iron accumulation or iron overload in certain tissues and organs can cause a host of health problems in children and adults including extreme fatigue, arthritis, joint pain, and severe liver and heart damage. Iron supplements often look like candy to children and can be lethal. Symptoms of toxicity can occur at doses of only 10-20 mg/kg of body weight.[16] It is critical to keep iron supplements out of children's reach.

There are also genetic disorders that lead to iron overload, even when iron intake is normal. Hemochromatosis is one of the more common and well known of these disorders. It occurs in about 1 in 150 people of northern European decent.[13] It is the result of a genetic mutation that leads to abnormal iron absorption and subsequent accumulation of iron in certain tissues such as the liver, pancreas, and heart. The signs and symptoms of hemochromatosis are similar to, but more severe than those of iron overload caused by high intake of iron. In men, hemochromatosis is typically observed by the age of 40, in women it may not be noticed until later in life (due to iron loses from menstruation). It may manifest as severe complications such as diabetes, scarring of the liver, cancer, arthritis or cardiac failure. Treatment for hemochromatosis includes regular blood removal, diet manipulations to reduce iron intake and absorption, and chelation therapy, which uses medications to remove excess iron from the body.[17]

Figure 9.16: A novel way to fight iron deficiency anemia. Image by LIFEintern under CC BY-SA 4.0 license.

The World Health Organization reports that 40% of pregnant women are iron deficient. Despite global efforts to provide iron supplements and fortify foods with iron, the incidence of iron deficiency anemia continues to be significant. The **Lucky Iron Fish** is a novel approach to improve iron status. It is a reusable cooking utensil made of ferrous iron that adds extra iron to meals. When added during the preparation of liquid meals a small but significant



amount of iron will release into the liquid as it is boiled. It has proven to be an effective way to reduce iron deficiency. It is estimated that regular use of the lucky iron fish in cooking can provide up to 75% of the iron needs of a woman in her reproductive years. The principle is the same as cooking with cast iron cookware, but the Lucky Iron Fish is convenient to use and more accessible to the populations in underdeveloped countries that are at high risk for deficiency.

- *What type of foods would increase the release of the iron into the food?*
- *Is this heme or non-heme iron?*
- *How could you increase the absorption of this type of iron?*

'LDSC/ CARE Benin - Protein for People' (Latter-Day Saints Charities/ CARE Benin – Protein for People project)

Zinc

Function

Zinc is a cofactor for roughly a hundred enzymes (possibly up to 200) and it is an important structural component of 1,000 or more transcription factors involved in gene expression.[18,19] With the diversity of zinc's functions, it is difficult to summarize the scope of its involvement in the human system. In brief, examples of zinc's involvement in the body include DNA and RNA synthesis, protein synthesis, immunity, carbohydrate metabolism, wound repair, hemoglobin synthesis and tissue and cell growth.

Food sources and bioavailability

Zinc is found in both animal and plant sources. It is more readily available from animal sources due to the common presence of binders in plant sources which decrease its bioavailability. One of the first observations that proved zinc was an essential mineral happened in 1958. A 21-yearold male from Iran presented with severe symptoms including dwarfism, delayed sexual maturation, dry rough skin, lethargy and an enlarged liver and spleen. His diet appeared to be adequate in calories and protein, but he ate little animal protein and all of his bread intake was unleavened bread. The phytates in the unleavened bread played a significant role in inhibiting the absorption of the zinc present in his food. He manifested with a fairly serious zinc deficiency. Once animal sources of zinc were included in his diet, all symptoms of the deficiency resolved.[20]

Animal sources of zinc include: Seafood such as oysters, lobster and crab, red meat, poultry and dairy products

Plant sources of zinc include: Whole wheat breads, fortified cereals, oatmeal, legumes, nuts and seeds and many green veggies



Figure 9.17: Foods high in zinc. Created by AP.

Deficiency and Toxicity

The effects of zinc deficiency are a worldwide concern, particularly in areas where the intake of red meat, seafood, and other animal sources of zinc is limited.[20] Considering the broad role of zinc in the human body, it is not surprising that the effects of zinc deficiency are varied. Symptoms such as impaired growth, diarrhea, delayed sexual maturation, and impaired immunity are common. Zinc deficiency may also manifest as skin lesions, poor fetal development, delayed wound healing, hair loss, poor appetite, and loss of taste.[19,21,22] Excessive intake of zinc can also be hazardous, causing significant intestinal distress such as cramping, nausea and vomiting, suppressed immunity, and interference with the proper function of copper and iron.[19,21]

Iodine

Function

Iodine is essential for the synthesis of thyroid hormones which regulate basal metabolism, growth, and development. The thyroid gland is located on the front of the neck just below the Adam's apple and in front of the trachea (windpipe). When dietary iodine is consumed, the majority is trapped within the thyroid gland. Seventy to eighty percent of the iodine in a human body is concentrated within the thyroid gland. [23]

Food sources and bioavailability

Most of the world's iodine is found in oceans. Over time it has been leached out of soils by flooding, erosion, and glacial action. Some of the iodine will vaporize from the oceans and be returned to the various land masses by rain fall, making coastal soils often richer in iodine.[2] The process of leaching and partial restoration of iodine from soils has left an uneven distribution of iodine in the world's soils, making plant foods an inconsistent source of iodine. Iodine levels can vary as much as 100 times, depending on the iodine content of the soil in which they were grown. [2] The presence of iodine in the oceans means that many types of seafood, such as seaweed and fish, are some of the richest sources of dietary iodine. In the United States, bread products and milk are the primary contributors of dietary iodine. In both cases, at least part of the iodine can be

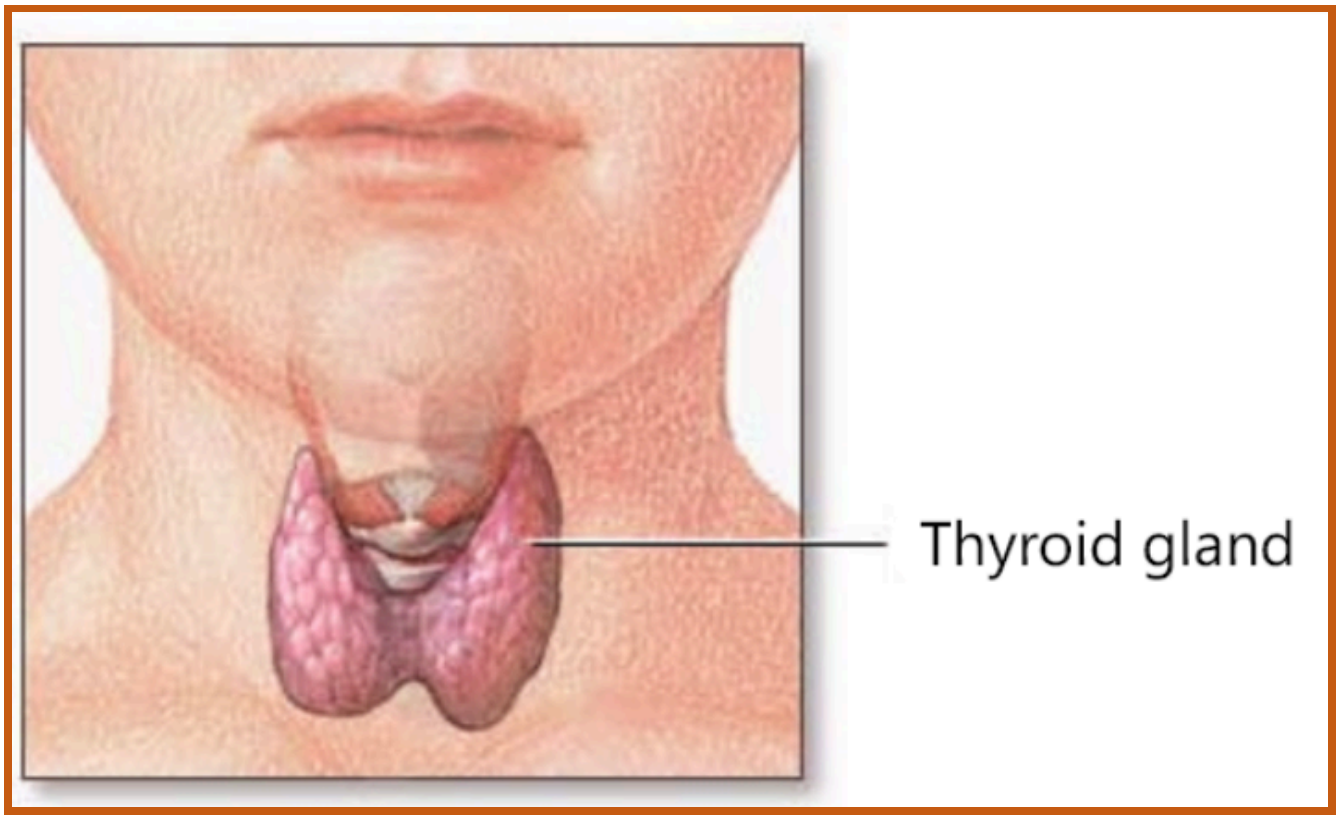


Figure 9.18: Thyroid. Image by BQUB16-Agil under CC BY-SA 4.0 license with edits.

attributed to either an addition of iodine during processing or contamination. Iodine containing sanitizing agents are often used in the milk industry to clean cow udders before milking, and in other stages of the milk processing. This makes a significant contribution to the iodine content of milk. Because of the issues of iodine distribution and the risk of deficiency globally, the iodization of salt has occurred in over 70 countries worldwide. It is a very inexpensive measure that has resulted in significant health benefits around the world. This practice was instituted in the United States in the 1920's and has been an important factor contributing to the low risk of iodine deficiency in the U.S.

Iodine is generally well absorbed, but there are substances that can interfere with the use of iodine in the body. These substances are called **goitrogens** and can be found in cassava, soy, and cruciferous vegetables such as kale, cabbage, broccoli, and cauliflower. While the consumption of these vegetables is certainly encouraged, it is also a reminder that moderation in all things is important. [2]

Figure 9.20: Cruciferous Vegetables. Created by AP.

Deficiency and Toxicity

The World Health Organization (WHO) reports that the incidence of iodine deficiency has diminished by 50% in the last 10 years, but 54 countries are still iodine deficient, impacting more than 2 billion people.[25,26] Iodine deficiency and the resulting hypothyroidism has many signs and symptoms, including fatigue, impaired mental function, sensitivity to cold, weight gain, depression, dry, itchy skin, and paleness. The development of **goiter** (enlargement of the thyroid gland) may often be the most visible sign of chronic iodine deficiency. While these symptoms are concerning, the larger problem occurs in children born to iodine deficient women. Low iodine levels during pregnancy impacts neural development in the developing baby and in severe cases will result in intellectual disability, deafness, mutism, and muscle spasticity. Collectively, the fetal effects of iodine



Figure 9.19: Sources of Iodine in the US. Image by Pavlofox via pixabay.



Figure 9.20: Cruciferous Vegetables. Created by AP.

deficiency are known as cretinism. Overall growth and life expectancy is also affected. Worldwide iodine deficiency is one of the major causes of impaired mental development. Excess iodine intake can result in symptoms similar to iodine deficiency.

Fluoride

Fluoride is not considered an essential nutrient. There has not been a specific deficiency associated with a lack of fluoride intake, nor has a specific biochemical function for fluoride been identified.[27] It has gained a place in the DRI recommendations because of its known role in combating tooth decay. The primary way it combats tooth decay is by increasing the strength of the enamel on teeth, making it resistant to decay. It is also recognized that fluoride inhibits the formation of acid from bacteria, and promotes the re-mineralization of teeth.



Figure 9.21: Cretinism and goiter in a female adult. Image by Dr. J.S.Bhandari, India under CC BY-SA 3.0 license with edits.

Trace amounts of fluoride are present in the human body, but levels of fluoride in food are generally low in all the food groups. A few exceptions include some fish and shellfish, tea, and a few grain products. Some water sources are also naturally high in fluoride, but most are not. Reaching levels recommended for protection against dental caries has been achieved through topical applications of fluoridated tooth pastes and rinses, supplements, fluoridation of water, and the consumption of foods produced with fluoridated water. Fluoride was first added to drinking water in 1945 in Grand Rapids, Michigan. The reduction of the incidence in cavities was so apparent its popularity spread rapidly. Now, nearly 75% of the US population has access to fluoridated drinking water. The Centers for Disease Control and Prevention (CDC) reports that fluoridation of water prevents, on average, 25% of cavities in children and adults.[28] Recommended levels are at 0.7 parts per million, but should not greatly exceed that. [29]

In addition to strengthening teeth, research is being conducted to assess if fluoride will also strengthen bone and possibly protect against osteoporosis. No evidence clearly supports this connection at this time. As with most nutrients, fluoride intake must be kept within appropriate levels. Extremely high doses of fluoride taken in a short amount of time can cause symptoms anywhere from nausea and vomiting to death. The likelihood of this happening is remote. More commonly seen is the discoloration of teeth that is a result from a mild chronic overconsumption of fluoride in children called fluorosis. It can range from white flecks in the teeth that are largely unnoticeable to more severe yellow to dark brown stains with possible pitting of the enamel. The incidence of fluorosis has been increasing in the US and other parts of the world since fluoridation of water was instigated. This can be prevented by ensuring proper intake of fluoride. Parents should consult with health



Figure 9.22: Women with a goiter. Image by Wellcome Library, London under CC BY 4.0 license with edits.

professionals when their children are young to correctly utilize fluoridated toothpastes and rinses and fluoride supplements in conjunction with the fluoride levels of the water in their community. Fluorosis can only develop in teeth before eruption from the gums, so primary prevention of fluorosis needs to be during the years of tooth development.

Additional essential trace minerals



Figure 9.23: Fluorosis. Image by MoninaCisneros under CC BY-SA 4.0 license.

Examples of function and food sources for the remaining trace minerals are summarized in Table 6. The listed information is by no means a comprehensive summary of each of the minerals, but is simply to demonstrate significant functions and food sources for these minerals. Generally, the functions of these minerals are carried out as cofactors to enzymes. Each of these minerals can be found in plant food, but the levels vary depending on the soil composition in which they were grown.

Trace Mineral	Example of a function	Some food sources
Copper	Regulation of iron antioxidant	Meats, shellfish, nuts, seeds, legumes
Molybdenum	Oxidation/reduction reactions	Meat, fish, poultry, legumes, grain products
Selenium	Antioxidant	Seafood
Chromium	Blood glucose regulation	Meat, fish and poultry, whole grains, dairy products
Manganese	Nutrient metabolism	Nuts, leafy vegetables, whole grains, legumes

Table 9.7: Functions and food sources of select trace minerals.[30]

Key Takeaways

- *Iron is essential for oxygen transport in the blood and muscles, and its deficiency is the most common nutritional disorder worldwide, causing symptoms like fatigue and weakness.*

- *Zinc is a crucial cofactor for hundreds of enzymes and is involved in a wider range of functions, including immunity, protein synthesis, and wound repair.*
- *Iodine is necessary for the synthesis of thyroid hormones that regulate metabolism. Its deficiency can lead to a visible enlargement of the thyroid gland (goiter) and, in pregnant women, can cause intellectual disabilities in the infant.*
- *Fluoride is not an essential nutrient but is highly effective at strengthening tooth enamel to prevent cavities. The fluoridation of public water has significantly reduced the incidence of tooth decay.*
- *The bioavailability of both iron and zinc is higher from animal-based foods than from plant-based foods due to natural inhibitors in plants.*

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6

Chapter 6: Water and Electrolytes

6.1. Introduction to Water

6.2. Water Balance

6.3. Electrolytes

6.4. Dietary Sources of Electrolytes

6.5. Electrolytes in Health and Disease

6.6. High Blood Pressure (Hypertension)

6.7. Evaluating Dietary Supplements

6.1

Introduction to Water

8.1 Introduction to Water



Figure 8.1: Desert plants and animals must conserve the water they acquire. Image by George Pagan III on Unsplash.

Water is essential for life, and maintaining proper hydration is crucial for survival. Both dehydration and excess water can impair body functions and eventually become fatal. The body can only survive a few days without water, making it the most immediately critical nutrient. Sensory proteins constantly monitor hydration status and send signals to the brain. By adjusting thirst and urine concentration, the body carefully regulates water balance.

Functions of Water

Water uses in the human body can be loosely categorized into four basic functions: transportation vehicle, medium for chemical reactions, lubricant/structural component and shock absorber, and temperature regulator.

Transportation

Water is truly an impressive substance. It has been called the "universal solvent" because more substances dissolve in it than any other fluid. Molecules dissolve in water because of the hydrogen and oxygen molecules ability to loosely bond with other molecules. Molecules of water (H_2O) surround substances, suspending them in a sea of water molecules. The solvent action of water allows for substances to be more readily transported. A pile of undissolved salt would be difficult to move throughout tissues, as would a bubble of gas or a globule of fat. Blood, the body's main transport fluid, is approximately **78 to 83 percent** water, depending on hydration status and individual factors. This high water content enables the efficient transport of nutrients, gases, hormones, and waste products throughout the body. [1]

Medium for Chemical Reactions

Water is required for chemical reactions to occur in the body. It serves as the transport vehicle that brings enzymes and compounds together and allows reactions to occur. Water is also used directly in the breaking and forming of some bonds. For example, when peptide bonds are formed (the bond that joins amino acids during the formation of proteins), water is produced; when the bond is broken, water is used.

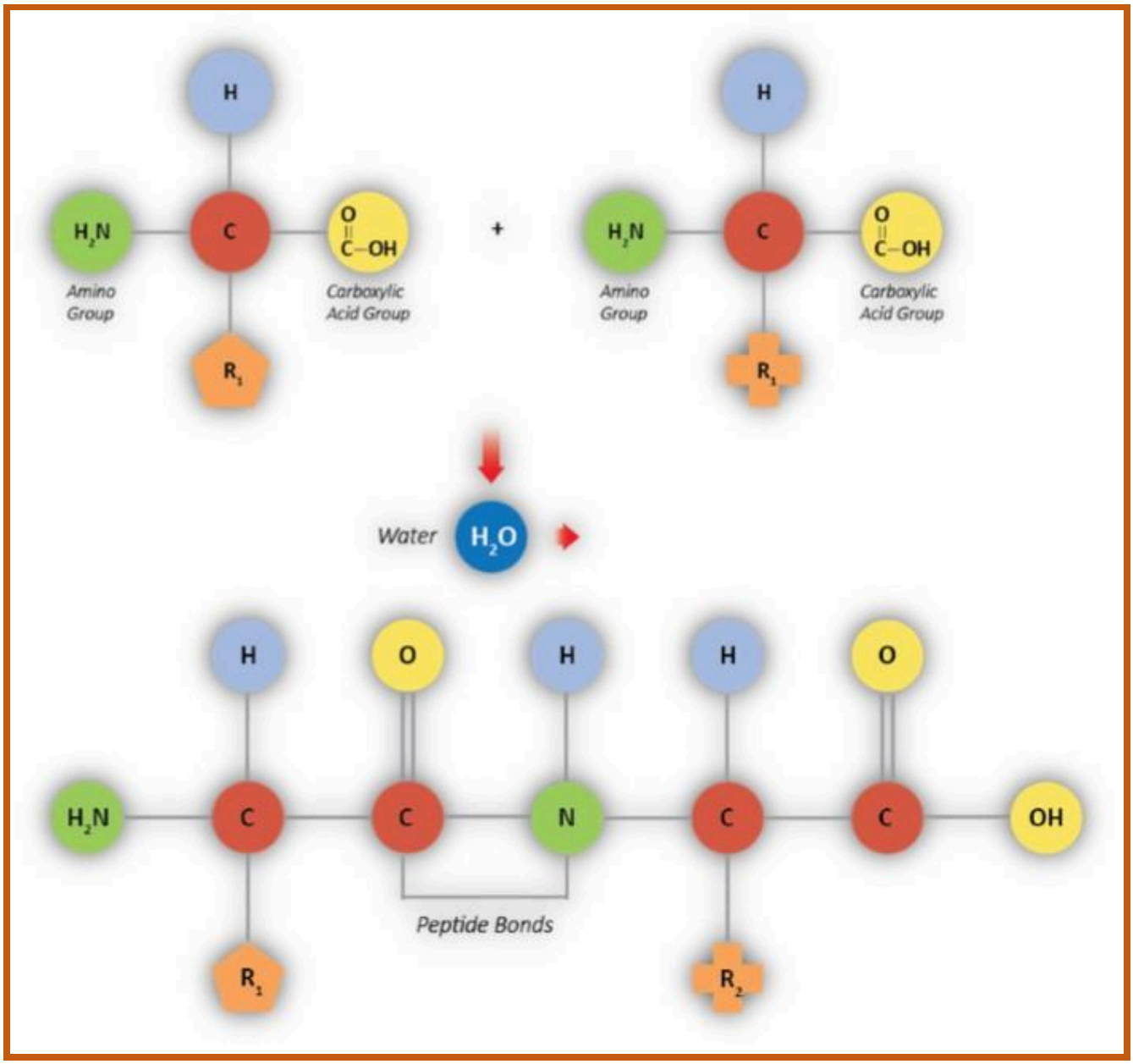


Figure 8.2: Release of water during the formation of a peptide bond

Lubricant, Structural Component and 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, but is also required for breathing, transportation of nutrients along the gastrointestinal tract, and elimination of waste material. Mucus is more than 90 percent water.

Water is also the main component of the lubricating fluid between joints. Movement would be painful without the lubricating and cushioning power of water.

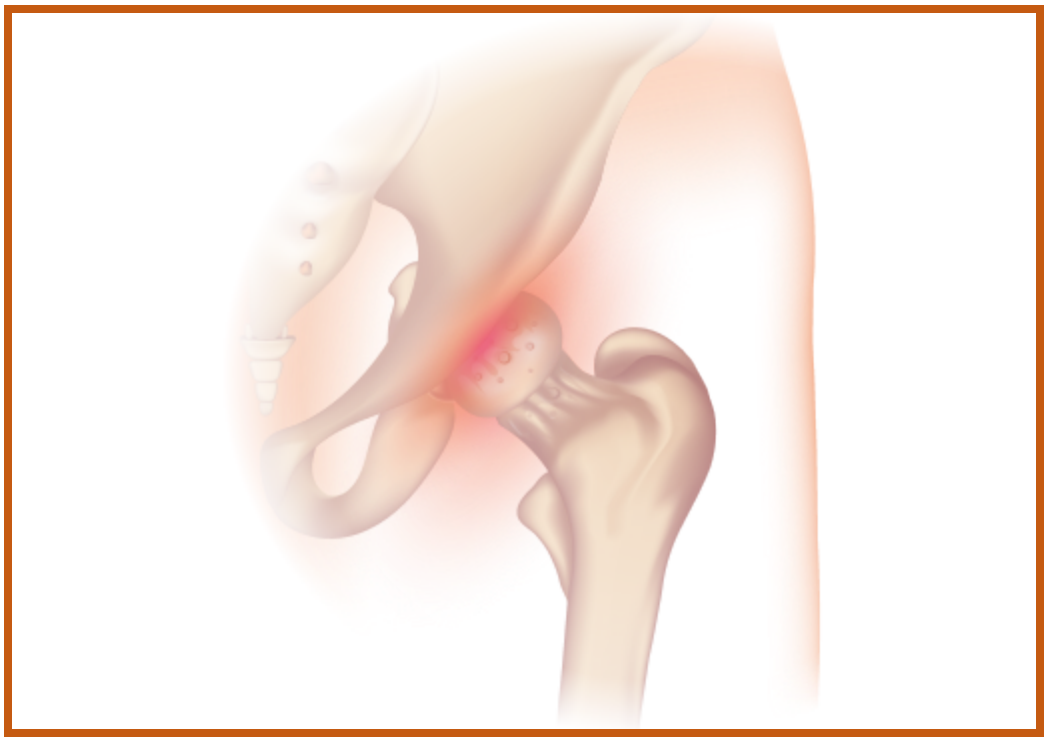


Figure 8.3: Transparent figure showing joint stress. Image by InjuryMap under CC BY-SA 4.0 license with edits.

Water is an important structural component throughout the body. The presence of water in every cell, the vascular system, spinal fluid and even the eye is important to maintain body structure. Without water, these structures would collapse. Its ability to assist cells, tissues and body cavities maintain shape is also central to water's role as a shock absorber. Just two weeks after fertilization, water fills the amniotic sac in a pregnant woman. Water has a variety of roles in pregnancy, but of central importance is its ability to provide a cushion of protection for the developing embryo.[1]

Water as a Temperature Regulator

It is well recognized that coastal cities tend to have more moderate temperature changes than do deserts. Large bodies of water can regulate the temperature of land masses because it has a capacity to absorb and emit large amounts of heat. Body water has a similar function. 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 temperature causes enzymes to stop functioning and metabolism to halt. If body temperatures are too low muscle failure occurs and hypothermia sets in. When body temperature is too high, the central nervous system fails and death results. We experience temperature changes each day, the presence of water in our body helps to minimize the effect of these changes. When the body begins to overheat (as might occur during exercise) the body releases water in the form of sweat. As the sweat evaporates from the body it dissipates large amounts of heat with it. Without this function of water, physical activity could quickly become lethal.[1]

Key Takeaways

- *Water is the most immediately critical nutrient for human survival, as the body can only survive for a few days without it.*



Man perspiring after exercise. Photo by Gantas Vaičiulėnas via Pexels.

- *It serves as a transportation vehicle, acting as a "universal solvent" to carry nutrients, hormones, and waste products throughout the body vie the bloodstream.*
- *Water is essential for chemical reactions, serving as a medium where compounds can interact and being directly used or produced in some reactions.*
- *It functions as a lubricant for joints, a key structural component for cells and tissues, and a shock absorber to protect the body.*
- *Water helps regulate body temperature by absorbing and releasing heat and by cooling the body through the evaporation of sweat.*

References (see more)

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6.2

Water Balance

8.2 Water Balance

On average, **50 to 70%** of an adult's body weight is water [5], making it the body's most abundant component. Approximately two-thirds of this water is inside cells (intracellular fluid), and one-third is outside cells (extracellular fluid), including blood, lymph, and spinal fluid.

Even small changes in fluid levels or composition can affect muscle function, kidney performance, pH balance, and temperature regulation. The brain, kidneys, nervous system, and hormones work together to monitor and adjust fluid balance as needed.[1]

Water Gains and Losses

Each day, water intake and output should be balanced. The body does an excellent job of maintaining fluid levels under normal conditions.

Water Out

Total fluid loss usually ranges from 2000 to 3000 milliliters/day, [1] but this can vary depending activity level and environment. Most fluid is lost through the kidneys, skin, and lungs, with smaller amount through the feces.

Typical Fluid Losses2

Kidneys	1500 milliliters
Skin	450 milliliters
Respiratory system	300 milliliters



Figure 8.4: Students walking together. Image by Eliott Reyna on unsplash.

Fecal	150 milliliters

Total = 2400 milliliters (~10 cups)

Water In

Fluid intake comes from drinking fluids, water in foods, and metabolic water (produced during the breakdown of carbohydrates, proteins, and fats).

Typical fluid intake to balance loses2

Fluid	1700 milliliters
Food	400 milliliters
Metabolic Water	300 milliliters

Total = 2400 milliliters (~10 cups)



Figure 8.5: A family eating together. Image by National Cancer Institute on Unsplash.

Many foods have surprisingly high water content. For example, watermelon is over 90% water, and even cooked salmon is about 60% water.

Food	Percent water
Watermelon	91%
Spinach	91%
Non Fat Vanilla Yogurt	79%
Pasta, cooked	62%
Salmon, Atlantic, cooked	60%
Cheddar cheese	37%
Almonds	4%
Peanut butter	1%

Table 1: Water content of selected foods

Regulating fluid intake

When body water is low, blood volume drops, and the concentration of dissolved substances (osmolarity) rises. These changes are sensed by the hypothalamus and kidneys, triggering thirst and hormonal responses to restore balance.

Hypothalamus

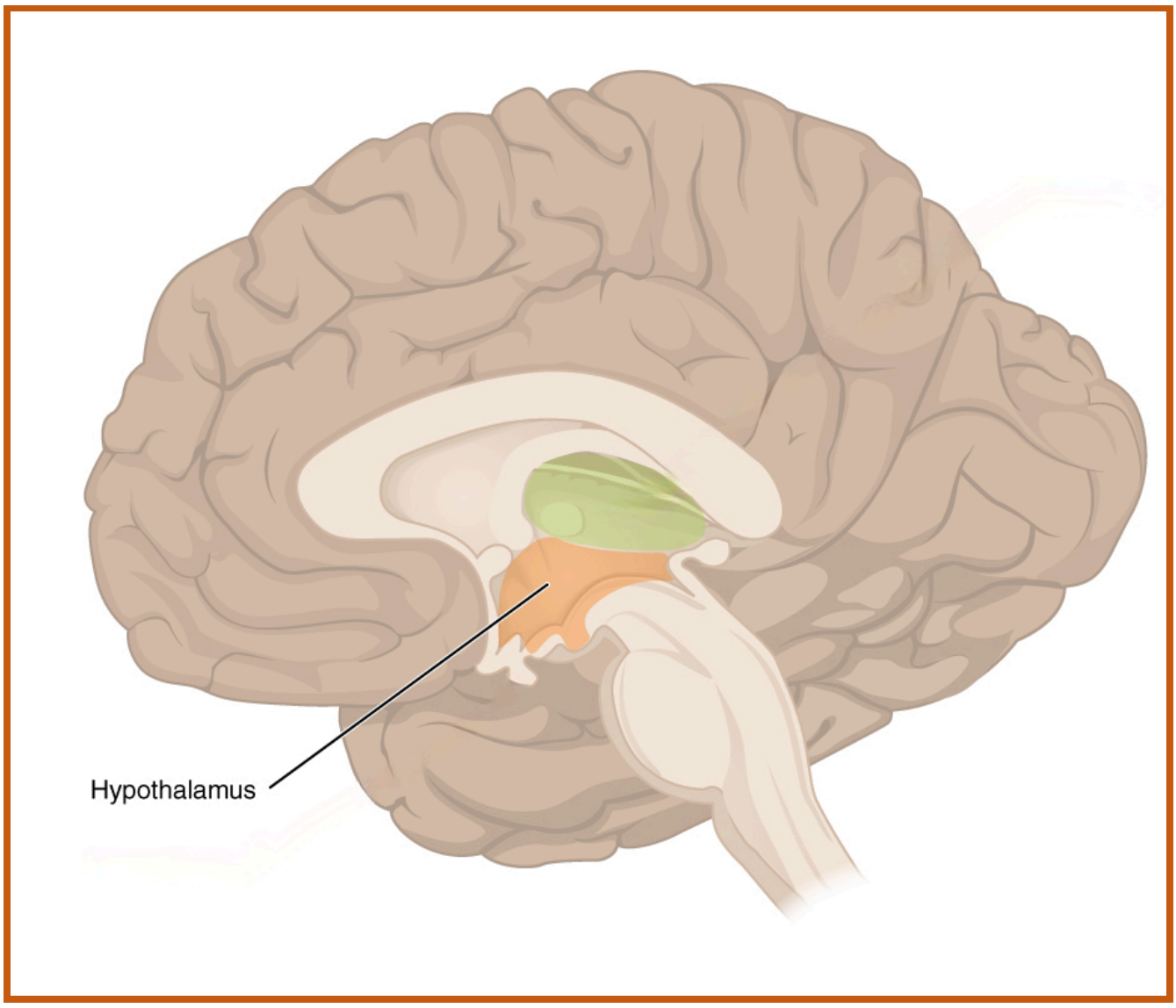
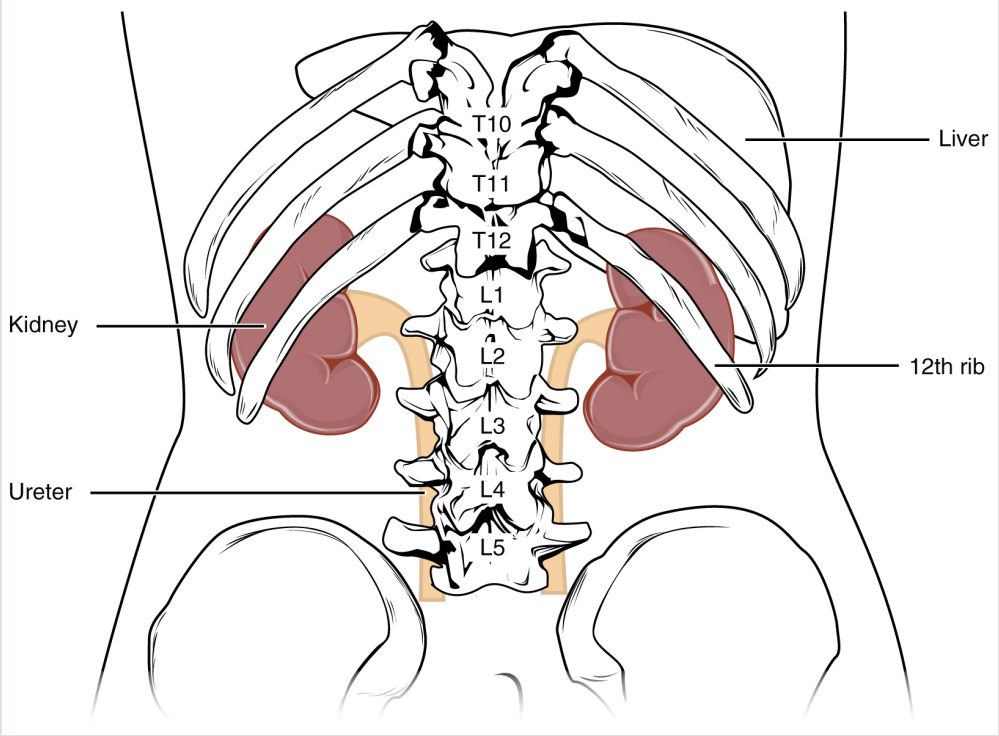


Figure 8.6: Hypothalamus helps to regulate fluid balance. Image by OpenStax under CC BY 4.0 license with edits.

The **hypothalamus** is known as the "thirst center." It detects increases in blood osmolarity and signals the urge to drink. It also stimulates the release of **anti-diuretic hormone** (ADH) from the pituitary gland. ADH prompts the kidneys to retain water and reduce urine output, helping restore fluid balance.

Kidneys

Figure 8.7: Transparent figure showing kidneys. Image by OpenStax College under CC BY 3.0 license with edits.



The **kidneys** filter blood, remove waste, and help regulate fluid levels. When blood volume or pressure drops, the kidneys release the enzyme **renin**. Renin activates **angiotensin**, which supports ADH release and stimulates thirst. Angiotensin also triggers the production of **aldosterone**, a hormone that promotes sodium and water retention in the kidneys.

In summary, the hypothalamus and kidneys work together using ADH, angiotensin, and aldosterone to maintain fluid balance through changes in thirst and urine output.

Figure 8.8: Regulation of fluid balance. Brain Image by OpenStax under CC BY 4.0 license with edits. The image of the person drinking water is by Mohamed_hassan via pixabay.

Water Recommendations

The Food and Nutrition Board recommends an **Adequate Intake (AI)** of 3.7 liters (15.6 cups) per day for adult males and 2.7 liters (11 cups) per day for adult females.[2] These amounts include water from all beverages and foods. About 20% of daily fluid typically comes from food, and 80% from drinks. Most healthy people can rely on thirst to meet their needs.

Dehydration



Figure 8.9: Athlete perspiring heavily. Image by RUN 4 FFWPU on pexels.

Daily recommendations are general and may not apply during exercise, extreme heat, or certain medical conditions. For example, athletes in hot weather can lose up to 2.5 liters (10 cups) of sweat per hour.[3]

Signs of mild dehydration include thirst, while more severe dehydration can cause muscle weakness, headache, irritability, dizziness, rapid heart rate, low blood pressure, delirium, loss of sweating, unconsciousness, and eventually death.

Populations at higher risk include athletes, older adults, and infants. High sodium, protein, or fiber diets can also increase fluid needs.

Monitoring Hydration

Urine color can be a helpful guide: pale yellow indicates adequate hydration, while dark yellow or amber suggests dehydration (see Figure 8.10).

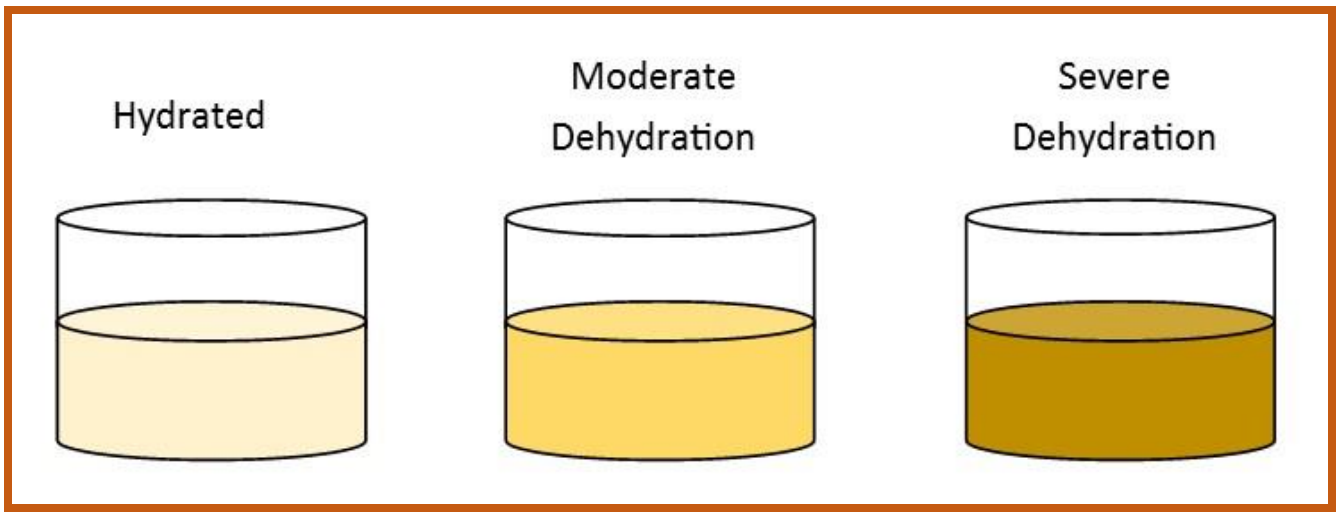


Figure 8.10: Urine hydration color chart

For athletes, tracking weight changes before and after practice can estimate fluid losses. Each pound (0.45 kg) lost equals about 2 cups (16 ounces) of fluid. It is recommended not to lose more than 2% of body weight from fluid during exercise.[3] To replace losses, gradually drink about 2.5 to 3 cups of water for each pound lost before the next session.

Over-hydration (Water Toxicity)

Drinking excessive amounts of water can be dangerous. When fluid intake exceeds the kidneys' ability to excrete it, blood sodium levels drop, leading to a condition called **hyponatremia,** meaning "low blood sodium". This causes water to move into cells, including brain cells, leading to swelling. Early symptoms include headache, confusion, and nausea. If not treated, it can progress to seizures, coma, or death.[4]

Although rare, this can occur in endurance athletes who drink large volumes of fluids without adequate sodium replacement or during water-drinking contests when excessive amounts are consumed quickly. [4]

Key Takeaways

- *An adult's body is composed of 50-70% water, with about two-thirds of this fluid located inside the body's cells.*
- *The body maintains water balance by regulating water intake from fluids, food, and metabolism, and output primarily through the kidneys, skin, and lungs.*
- *The hypothalamus and kidneys work together to regulate fluid balance by triggering thirst and adjusting urine output using hormones.*
- *Dehydration, caused by a lack of water, can lead to symptoms ranging from thirst to more severe issues like muscle weakness, dizziness, and low blood pressure.*
- *Over-hydration is also dangerous and can lead to hyponatremia (low blood sodium), a condition that can cause cells to swell and may be fatal.*

References (see more)

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6.3

Electrolytes

8.3 Electrolytes

When discussing body fluids and fluid balance, sodium, potassium and chloride are typically the electrolytes of primary interest. An **electrolyte** is a positively or negatively charged inorganic compound that when in solution is capable of conducting electrical currents. They are a significant player in maintaining the body's fluid balance and in neuron function. Electrolytes that are positively charged are called **cations** (+) while negatively charged electrolytes are called **anions** (-). Sodium (Na^+) is positively charged and is primarily located on the outside of cells. Potassium is positively charged and is found primarily inside cells (K^+). Chloride is negatively charged and located primarily outside of cells (Cl^-). Knowing the main location of the electrolytes in the body is important. For example, when a person sweats heavily, we know that the sweat is produced from fluid outside cells; as a result, large amounts of sodium and chloride are lost and much lower levels of potassium. Understanding this principle allows for the development of the best strategies to replace sweat losses. The body is able to maintain the distribution of the electrolytes using pumps that move the electrolytes across membranes.

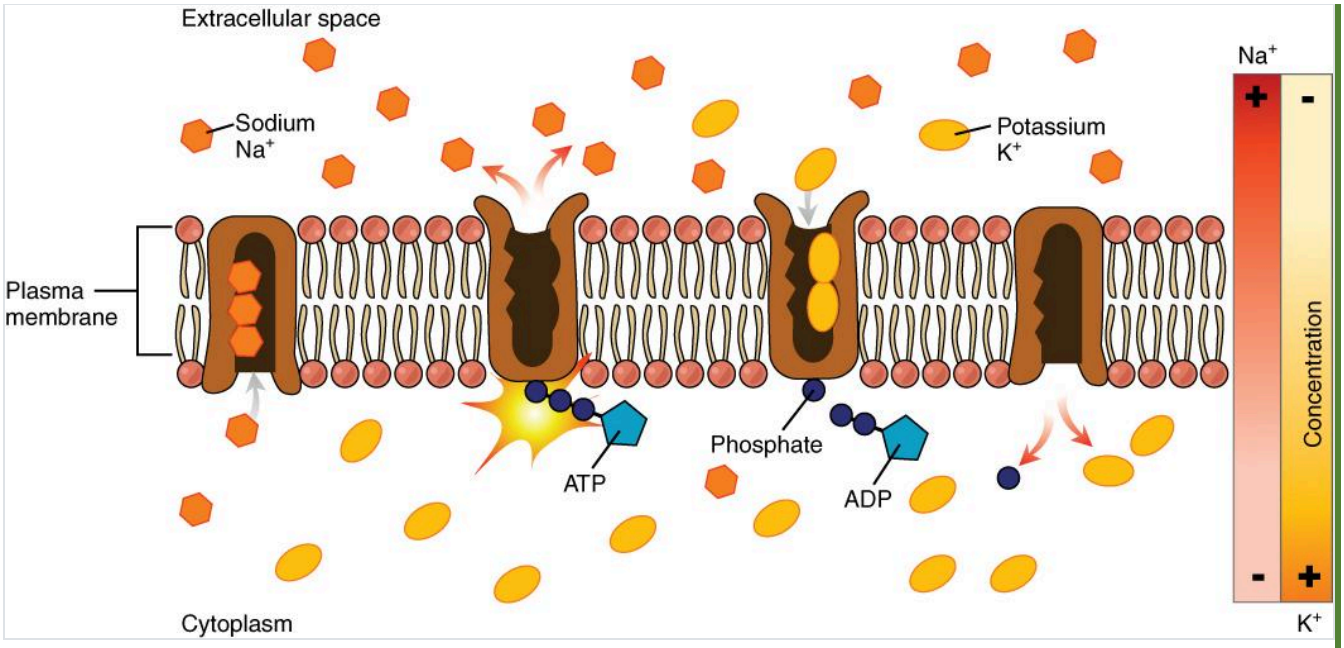


Figure 8.11: The distribution of the cations sodium and potassium in the body. Image by OpenStax under CC BY 4.0 license.

Functions of Electrolytes

Fluid Balance

The movement of water across semipermeable membranes, also known as **osmosis**, is affected by the amount of electrolytes and other substances dissolved in the fluids. This principle is applied in the body in the regulation of fluid balance and is displayed in Figure 8.12. Salt water, which is high in sodium chloride (salt), pulls the fresh water across the membrane. The amount of force exerted by the salt water is called the **osmotic pressure**.

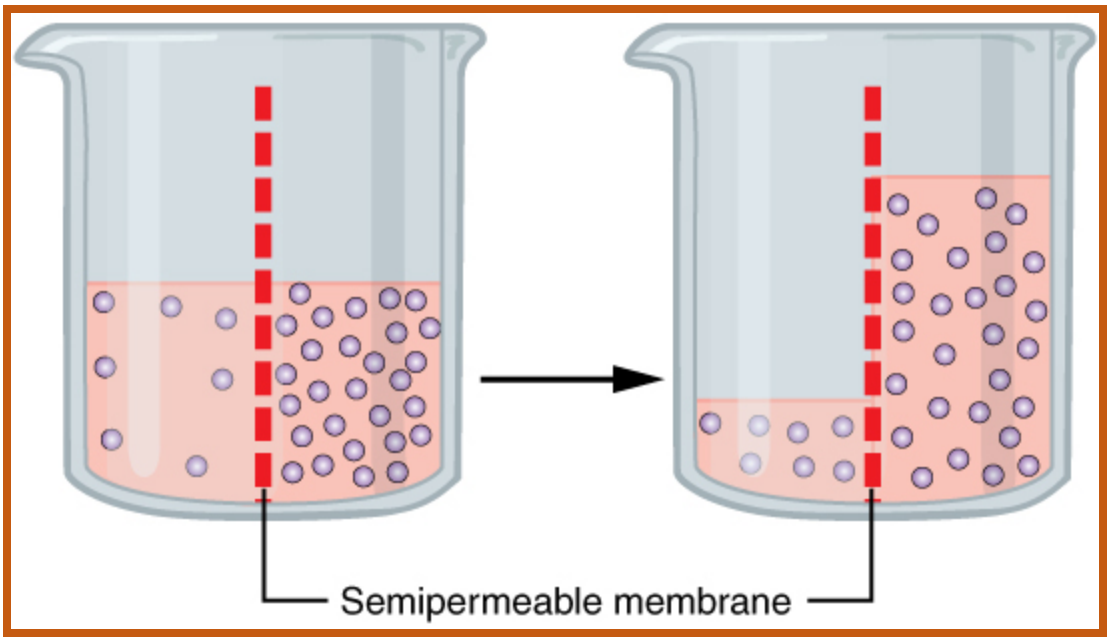


Figure 8.12: Movement of water across a semipermeable membrane. Image by OpenStaxs under CC BY 4.0 license.

The body is able to pump electrolytes and other substances across membranes in the body in such a manner that maintains fluid balance. Water will follow the movement of the electrolytes. Disruptions in the system can be manifested in a number of ways. One example of a disruption in the fluid balance system is the presence of edema.

Nerve Conduction

The nervous system uses electrolyte pumps to maintain a high level of sodium outside of the nerve cell and a high level of potassium inside the cell. A gradient such as this represents potential energy. It is not natural for the electrolytes to stay separated in this manner in fluid systems. It takes energy to keep it this way. A nerve impulse is initiated when a sufficient stimulus opens gates on the nerve and lets the sodium and potassium rush across the membrane. This starts a process that allows a message to be moved down a nerve. Once the signal is ended, sodium and potassium pumps are able to restore the sodium/potassium gradient (see Figure 8.13).

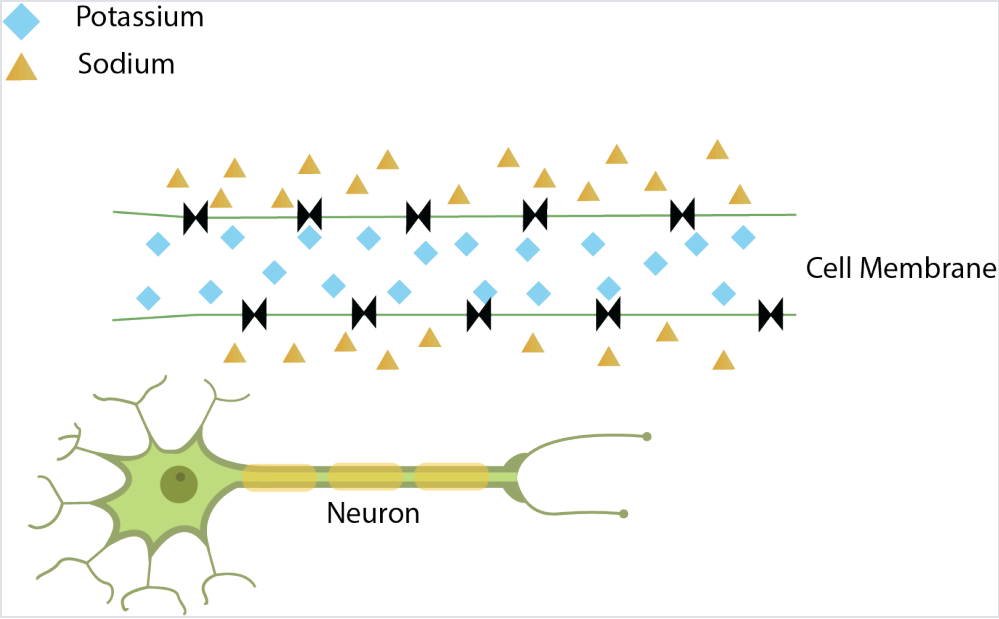


Figure 8.13 : Electrolytes role in nerve conduction. Created by AP.

Electrolytes are also involved in the contraction of muscles and in the transport of some nutrients; for example, sodium is necessary for the active transport of glucose in the small intestine.

Control of Electrolyte Levels

Considering the important function of electrolytes, it is vital that the body has methods for regulating levels. The hypothalamus and kidney have sensors that detect changes in blood osmolarity. The brain will initiate thirst in an effort to dilute the blood if osmolarity is high and the kidney can retain or increase the excretion of solutes as needed. For example, after a meal high in salt (sodium-chloride), sodium and chloride levels increase in the blood. Sensing this, the brain induces a drive to drink and the kidney increases the excretion of sodium. By so doing sodium balance is restored. In some people the increase in fluid intake associated with the high sodium intake can temporarily increase blood pressure. In an effort to dilute sodium levels the body becomes temporarily fluid overloaded which increases the volume of blood in the blood vessels.



Figure 8.14: Foods high in sodium includes fast foods and snacks. Created by AP.

The increased volume in the blood vessels can increase pressure. The fluid retention can also show up on the scale as a small change in weight. Ideally the kidney will increase urine production quickly and make the necessary adjustments in body fluid levels

Drastic changes in blood electrolyte levels are life threatening. Heavy sweating, prolonged and intense diarrhea and vomiting, certain medications and pH problems are all examples of situations that might raise or lower specific electrolytes and may require prompt medical treatment.

Key Takeaways

- *An electrolyte is a charged compound that helps maintain the body's fluid balance and is crucial for proper nerve function.*
- *Sodium is the primary electrolyte outside of cells, while potassium is the primary one inside cells.*
- *The movement of water across cell membranes (osmosis) is controlled by the concentration of electrolytes, which helps the body maintain fluid balance.*
- *Electrolytes create and maintain the electrical gradient necessary for nerve impulses and muscle contractions.*
- *The body tightly regulates electrolyte levels, as drastic changes from conditions like heavy sweating, vomiting, or diarrhea can be life-threatening.*

References (see more)

6.4

Dietary Sources of Electrolytes

8.4 Dietary Sources of Electrolytes

Sodium

The Food and Nutrition Board of the National Academy of Medicine has set the adequate intake (AI) for sodium at 1500 mg per day and a maximum recommended intake of 2300 mg per day.[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, and just over 1 teaspoon of salt will reach the UL. When sweating and other mediums of sodium loss are at a minimum, needs can be as low as 200 mg per day[2] . It is important to emphasize that sodium is an essential dietary nutrient. It has functions that are critical for health and survival. Emphasis is usually focused on over-consumption of sodium because under normal circumstances, with typical dietary intake, inadequate sodium intake is unlikely, but in many regions of the world over-consumption is common. In the United States, it is estimated that on average individuals consume greater than 3400 mg of sodium per day.[4] Sodium does occur naturally in many foods, but the primary source of this sodium in the U.S. is added sodium in processed foods (Table 2).

Less Processed		More Processed	
	1cup feash tomatoes: 7mg		1/2 cup tomato sauce: 581 mg
	3 ounces' pork roast: 57mg		1 ounce pepperoni: 448 mg
	1 cup milk: 107 mg		2 ounces processed cheese: 936 mg
	1 medium baked potato: 8 mg		Medium French Fry: 221 mg

Table 2: Comparison of the sodium content of foods. Tomatoes image by Anelka on Unplash. Tomato Sauce image by Tjena on Unplash. Steak image by RitaE on Unplash. Pepporoni image by Payam Tahery on unsplash. Milk image by an_vision on unsplash. Cheese image by Hyeon-Jeong Suk under CC BY 2.0 license with edits. Potato Image by hkama via pixabay. Fry Image by Mockup Graphics on unsplash.

A fresh meat (3 ounces), baked potato (medium) and fresh vegetable (3/4 cup) with a glass of milk with no added salt would have about 200 mg of sodium. In contrast a meal including more highly processed foods such 3 slices of pepperoni pizza with fries and a 16-ounce soda would typically have closer to 2800 mg of sodium. Even after butter is added to the baked potato and the low processed meal is lightly salted it will still be well below the sodium level of the more processed meal. Food producers are required by law to list the amount of sodium contained in their product on the food label and is a good way to monitor sodium intake. It is also helpful to know that claims such as "low sodium" or "reduced sodium" are legally defined and can only be used when certain criteria are met (see Table 3).

Label Descriptor	Definition
Sodium Free	Less than 5 mg of sodium per serving
Very Low Sodium	35 mg of sodium or less per serving
Low Sodium	140 mg of sodium or less per serving
Reduced Sodium	At least 25% less sodium than the regular product
Light/Lite	At least 50% less sodium than the regular product

Table 3: Sodium descriptors on labels[5]

Potassium



Figure 8.15: Healthy foods rich in potassium. Created by AP.

During processing the level of sodium often increases in food. In contrast the amount of potassium often decreases. A good dietary intake of potassium may be protective against high blood pressure and related problems such as heart disease and stroke. For adult males and females above the age of nineteen, the adequate intake for potassium is 2.6 grams per day for females and 3.4 grams per day for males. [2]

Fruits and vegetables that contain high amounts of potassium are spinach, broccoli, peas and legumes, tomatoes, potatoes, bananas, apples and apricots. Whole grains and seeds, certain fish (such as salmon, cod, and flounder), and meats and dairy are also high in potassium. The Dietary Approaches to Stop Hypertension (DASH diet) emphasizes potassium-rich foods and will be discussed in greater detail in the next section.

Chloride

Most chloride in the diet comes from salt and therefore from processed foods. (Salt is 60 percent chloride.) A teaspoon of salt equals 5.6 grams, with each teaspoon of salt containing 3.4 grams of chloride and 2.2 grams of sodium. The chloride AI (adequate intake) for adults, set by the National Academy of Medicine, is 2.3 grams. [2] Therefore, just ⅔ teaspoon of table salt per day is sufficient for chloride as well as sodium. Chloride may also be found in small amounts in some foods independent of sodium; instead it can be bound to potassium as the salt potassium chloride. Some salt substitutes will use potassium chloride as a replacement option for sodium chloride.

Key Takeaways

- *The average sodium intake in the United States (over 3400 mg/day) is well above the recommended maximum of 2300 mg per day.*
- *The primary source of sodium in the American diet is added sodium from processed foods, not naturally occurring sodium.*

- *While sodium levels increase during processing, the amount of potassium in food often decreases.*
- *A good intake of potassium from foods like fruits, vegetables, and whole grains may help protect against high blood pressure and heart disease.*
- *The main dietary source of chloride is table salt, which is sufficient to meet daily needs for both sodium and chloride.*

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6.5

Electrolytes in Health and Disease

8.5 Electrolytes in Health and Disease

Electrolyte Imbalances

Maintaining normal electrolyte levels in body fluids is essential for life. Changes in sodium and potassium levels are a primary focus when electrolyte imbalances are discussed, but other electrolytes such as calcium and magnesium have important roles as well. When electrolytes are out of balance, prefixes such as hypo and hyper are used to indicate the direction of change. For example, low blood sodium and potassium levels are referred to as hyponatremia and hypokalemia, respectively. High blood sodium and potassium are referred to as hypernatremia

and hyperkalemia, respectively. Changes in blood sodium and potassium can be very serious and may be brought on for a variety of reasons. Changes in blood pH, diarrhea, vomiting, medications, kidney problems, hormonal imbalances, inadequate or excessive fluid intake, and even excessive bleeding can affect electrolyte levels.[6] Sweating can be a common cause associated with electrolyte imbalances. Because sweat is made from extracellular fluid (sodium is high in extracellular fluid) sodium imbalance is a common concern with heavy sweating. Replacing heavy sweat losses with pure water, or over consuming fluid can both lead to hyponatremia. In most cases, sodium losses incurred by sweating can be replaced through regular dietary intake, but sodium intake levels above the UL may be needed to replenish losses. In situations of prolonged sweating in hot environments, electrolyte replacement may be necessary during the activity. Recommendations will vary depending on individual sweat rates, sweat salt levels (amount and composition of sweat various significantly from person to person), environmental conditions and length of exercise.[6] The symptoms of hyponatremia include headache, personality changes, irritability, nausea, muscle twitching, and in severe cases, seizures, coma and death.[6]

Key Takeaways

- *Maintaining normal electrolyte levels, especially sodium an potassium, is vital for life.*
- *Imbalances such as hyponatremia (low blood sodium) and hyperkalemia (high blood potassium) can be caused by factors like vomiting, diarrhea, or excessive sweating.*
- *Heavy sweating causes a significant loss of sodium, as sweat is produced from the fluid outside of cells.*



Water alone does not replace electrolyte loss. Image by Nigel Msipa on Unsplash.

- *Replacing heavy sweat losses with plain water or over-consuming fluid can lead to the dangerous condition of hyponatremia.*
- *Symptoms of hyponatremia can range from headaches and nausea to more severe conditions like seizures, coma, and even death.*

References (see more)

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6.6

High Blood Pressure (Hypertension)

8.6 High Blood Pressure (Hypertension)


ARTERY



Healthcare professional taking a patient's blood pressure

Blood pressure is the force of moving blood against arterial walls. It is reported as the systolic pressure over the diastolic pressure. The **systolic** number indicates how much pressure is exerted on the artery wall while the heart is beating. The **diastolic** number indicates how much pressure is exerted on the artery wall while the heart is at rest. The force of blood against an artery is measured with a blood pressure monitor. The results are recorded in millimeters of mercury, or mmHg. A **desirable blood pressure range** is less than 120/80 mmHg.[8] There is a condition called **Hypotension** which is defined as a blood pressure lower than 90/60 mmHg. Adequate but not excessive intake of fluids and sodium can help maintain a healthy blood pressure. **Hypertension** is high blood pressure and defined as a sustained blood pressure of 130/80 mmHg or greater (see Table 4).

Blood Pressure Category	Systolic (mm Hg)		Diastolic (mm Hg)
Normal	Less than 120	AND	Less than 80
Elevated	120-129	AND	Less than 80
High Blood Pressure (hypertension) Stage 1	130-139	OR	80-89
High Blood Pressure (hypertension) Stage 2	140 or higher	OR	90 or higher

Table 4: Blood pressure ranges countries created by AP

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 American Heart Association reports that over 85 million Americans have high blood pressure and nearly 20% don't even know they have it.[8] It is often referred to as a silent killer since most often there are no symptoms associated with high blood pressure until significant physical damage has occurred.[8] The constant increased pressure in the blood vessel system that is associated with high blood pressure can not only damage the blood vessel system and heart, but other organs as well, such as the kidneys and eyes. There are a variety of risk factors associated with the development of high blood pressure, which include: [9]

- Age (older adults are at higher risk)
- Ethnicity (e.g. African Americans are at higher risk than Caucasians)
- Overweight or Obesity
- Gender
- Lifestyle habits (physical activity, alcohol consumption, diet, etc.)
- Family history

Many of the risk factors associated with developing high blood pressure are not within a person's control, but some are; lifestyle habits and body weight can be influenced by personal choices. Dietary patterns are recognized as influential in preventing and treating high blood pressure. Dietary recommendations include limiting sodium intake, limiting alcohol intake,

controlling caloric intake to maintain a healthy weight and general principles that promote heart health such as choosing whole grains, a wide variety of fruits and vegetables and lean protein sources, with an emphasis on plant proteins such as legumes, fish, nuts and seeds and limiting saturated fats and added sugars. These principles have been collected into an eating plan referred to as DASH (Dietary Approaches to Stop Hypertension). Clinical trials using the DASH Eating Plan in comparison to a typical American diet, have shown reduction in blood pressure, weight and LDL cholesterol levels.[10,1]

The DASH Eating Plan is rich in calcium, magnesium, potassium, fiber and protein and low in sodium, added sugars and saturated fats.

Food Group	Recommendations	Serving Size Examples
Grains (whole grains are recommended)	6-8 servings	1 slice (1 ounces) bread 1 ounce of dry cereal 1/2 cup cooked rice, pasta, or cereal
Vegetables	4-5 servings	1 cup raw leafy vegetables 1/2 cup raw or cooked vegetables 1/2 cup vegetable juice
Fruits	4-5 servings	1/4 cup dried fruit 1/2 cup fresh, frozen or canned fruit 1/2 cup vegetable juice
Fat free or low-fat milk products	2-3 servings	1 cup milk or yogurt 1 1/2 ounces of cheese
Lean meats, poultry, fish and eggs	6 servings or less	1 ounce of cooked lean meats, or fish 1 egg
Nuts, seeds, and legumes	4-5 servings per week	1/3 cup or 1 1/2 ounces nuts 2 tablespoons peanut butter 1/2 cup cooked legumes (dry beans/peas)
Fats and oils	2-3 servings per day	1 teaspoon soft margarine 1 teaspoon vegetable oil 1 tablespoon mayonnaise
Sweets and added sugars	5 servings or less per week	1 tablespoon sugar 1 tablespoon jelly or jam 8 ounces lemonade

Table 5: DASH Eating Plan for the 2000 Calorie level [12]

How the DASH Eating Plan so rapidly reduces blood pressure is still not clear. Speculation has focused on the mineral content of the plan. The high potassium, calcium and magnesium and low sodium content of the DASH eating style can by physiologically justified as a contributor in the observed reduction in blood pressure. Recent evidence has also shed light on another possible mechanism. Many vegetables are rich in nitrates. Mounting evidence supports a significant effect of nitrates on blood pressure levels; the increase in nitrate intake associated with a DASH eating style may be a key component in the quick effect on blood pressure that is observed when this style of eating is adopted.[13]

Key Takeaways

- *Hypertension is defined as a sustained blood pressure of 130/80 mmHg or higher. Over 85 million Americans have high blood pressure, and nearly 20% are unaware of their condition.*
- *Often called a "silent killer," high blood pressure typically has no symptoms until it has caused significant damage to the heart, blood vessels, and other organs.*
- *The DASH Eating Plan is a dietary approach clinically proven to reduce blood pressure, weight, and LDL cholesterol.*
- *The DASH diet is rich in calcium, magnesium, and potassium, and low in sodium, added sugars, and saturated fats.*
- *Key dietary recommendations for preventing and treating high blood pressure include limiting sodium and alcohol, maintaining a healthy weight, and focusing on whole grains, fruits, vegetables, lean proteins, and unsaturated fats.*

References (see more)

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6.7

Evaluating Dietary Supplements

8.7 Evaluating Dietary Supplements

When to Choose a Supplement

Before discussing how to choose and evaluate dietary supplements, it is important to explore how they are best used, what they can do, and what they don't do. This discussion will focus on vitamin and mineral supplements as opposed to other types of dietary supplements such as herbal supplements. In the Dietary Guidelines for Americans 2020 it states that nutritional needs should be met primarily by food.[10] Vitamin and mineral supplements should not be viewed as a means to compensate for a poor dietary intake in most cases. When supplements are used to cover up a poor diet, they may prevent deficiencies of specific vitamins and minerals. However, they will not compensate for the health impact of poor dietary choices, such has high amounts of added sugars or saturated fats, or low fiber intake. It also will not provide all the other health promoting non–nutrient compounds that are found in food, such as the phytochemicals. When a person fully understands all the ways good food choices impacts health, the recommendation to choose food over supplements is easily understood.

With that preface, it is important to understand there are also times vitamin and mineral supplements are an excellent tool to promote health. In the Dietary Guidelines for Americans, 2020 it also states "In some cases, When meeting nutrient needs is not otherwise possible, fortified foods and nutrient containing dietary supplements are useful."[10] Vitamin D supplements for people living at high latitudes in the winter is an example of appropriate use of supplementation. The 37th parallel is the cutoff typically used. This is roughly a line from San Francisco to Richmond, Virginia. Those living above this line may struggle with Vitamin D synthesis in winter months.[14] It can be difficult for many cultures to get adequate vitamin D from natural food sources. Fortified foods and supplements can be an important tool to maintain adequate Vitamin D levels when sun exposure is not adequate. Genetic conditions or specific health problems may also necessitate some types of supplementation. During pregnancy, iron and folic acid supplementation are often recommended to ensure the needs of the developing infant and mother are met. These are examples of specific situations where supplements are used to meet a clearly identified need. The elderly, vegan vegetarians, people with malabsorptive conditions or on calorie restrictive diets are additional examples where certain forms of supplementation may be beneficial.

Choosing a Supplement



Dietary supplements may be taken as pills and capsules. Image by Mika Baumeister on Unsplash.

When choosing a supplement there are several important matters to consider. First, as already discussed, be sure there is an identified need not being met by a balanced diet. If a need is identified, then there are several important considerations to reflect on when making a selection.

Quality of vitamin and mineral supplements

Unlike drugs, under most circumstances proof of effectiveness and safety of dietary supplements does not have to be submitted to the Food and Drug Administration (FDA) before the supplement is marketed. If any supplement appears to be harmful, the FDA can require the product be removed, but only after evidence is secured. The FDA has established good manufacturing practices that have been designed to help prevent the inclusion of wrong ingredients, inaccurate levels of ingredients and contamination. Companies are required to follow these practices. The FDA does inspect facilities to see if these practices are followed, but policing the industry as a whole is largely impossible. It is logical, that generally supplement companies work to produce a good supplement, but research has shown that quality/purity of supplements do vary, sometimes dramatically and on a rare occasion in a manner that is harmful. [15,16] From a consumer standpoint, it is difficult to discern which supplements may be a problem. There are several private agencies that offer testing to supplement companies. These companies include: [17,18]

1. U.S. Pharmacopeia
2. ConsumerLab.com
3. NSF International

If asked by the supplement company, these agencies will test their product to verify that the product does not contain harmful levels of contaminants, contains what the labels states is in the product and that it will dissolve well in the intestinal tract. 10 If a product carries the seal of approval from one of these companies, the consumer can be assured this level of quality has been met. It does not, however, verify the supplement is effective or safe.

The FDA and **Federal Trade Commission** also monitor supplements to ensure that claims on labels and package inserts are truthful and not misleading. [10]

Safety and effectiveness of vitamin and mineral supplements

Vitamin and mineral supplements are biologically active agents and need to be treated with respect. If a person is pregnant, nursing, taking medications or has other special health conditions it may be best to consult with a health care provider about supplements you may be considering. For example, supplementation of certain vitamins and minerals may enhance or inhibit the action of some medications. Certain health conditions may warrant fairly high doses of certain vitamins and minerals and need to be prescribed by a health care provider and tolerance monitored over time. Under normal circumstances a consumer can use the supplement label to help them make wise decisions about the choice of a supplement. Selecting a supplement with 100% or less of the Daily Value (DV) is a wise standard to use. It is important to recognize the intakes of vitamins and minerals above the RDAs and AIs are not generally recognized to be beneficial in a healthy person; nor have taking supplements in general been shown to have health benefits. But if a supplement is chosen with this guideline in mind, it is not likely to be harmful either (see Figure 8.16).



Figure 8.16: A vitamin and mineral supplement supplying 100% or less of the DV of selected nutrients. Bottle image by Supliful - Supplements On Demand on Unsplash.

If a supplement does contain greater than 100% of the DV, it is wise to check the contents against the Tolerable Upper Intake Level (UL) for that nutrient. To do this you will need a copy of the DV and UL tables. In Figure 8.17 it shows that vitamin B6 is at 5000% of the DV. The amount of vitamin B6 in the supplement is 100 milligrams. The UL for B6 shown in the DRI tables is 100 mg for a young adult. This supplement contains the UL for vitamin B6 before any consideration has been made for dietary intake.



Figure 8.17: A vitamin and mineral supplement supplying greater than 100% of the DV for some of the selected nutrients. Image by Supliful - Supplements On Demand on Unsplash.

Even if the nutrient does not exceed the UL, high doses of nutrients should be approached with some caution. Today's food supply is heavily fortified with vitamins and minerals. Some products contain enough added vitamins and minerals they could be viewed as a supplement. To assess safety, a person should consider their current dietary intake, use of fortified foods, as well as the levels of nutrients in any supplement that may be used. For example, many cold cereals may contain fortification up to 100% of many, if not most all the vitamins and minerals. Serving size is typically around ¾ cup. It would not be uncommon for some people to eat several servings at one meal, and may have cereal on several occasions within a day. For a few nutrients, the cold cereal alone may put them over the UL.

Other Dietary Supplements

Vitamin and mineral supplements are not the only types of dietary supplement that can be found on the market. They include a number of other types of products, such as herbal supplements and are regulated under the same guidelines as vitamin and mineral supplements. The number of herbal supplements available makes it unreasonable to adequately cover the topic in this material. In addition, herbal supplements can contain powerful biologically active agents; and should be treated with care. Just because they come from plants, doesn't make them safe. Herbal supplements have the same questions and concerns regarding quality and purity as vitamin and mineral supplements. Also, because they are typically derived from plants the amount of active agent in the plant may not be clear to the consumer. The level of active agent can vary depending on the conditions where the plant was grown. If used, dosage should be carefully researched, and use of herbal supplements in pregnancy, with medications or other herbals, or when other health conditions are present, should be discussed with a health professional. The National Institute of Health has developed a website that summarizes what is known about a number of commonly used herbal products, but it does not address dosage recommendations.[19] In summary, if used, select herbal supplements with care and in conjunction with your health professional if needed. Other types of supplements include amino acids and tissue extracts.



Loose herbs and pills. Image by JerzyGorecki via Pixabay.

Key Takeaways

- *Vitamin and mineral supplements should be used to address specific nutrient needs that cannot be met by food, not to compensate for a poor diet.*
- *The FDA does not approve supplements for safety or effectiveness before they are marketed, so their quality and purity can vary.*
- *To help ensure a supplement's quality, look for a seal of approval from independent third-party agencies like U.S. Pharmacopeia, ConsumerLab.com, or NSF International.*
- *For a healthy person, a wise standard is to choose a supplement that contains 100% or less of the Daily Value (DV) for each nutrient.*
- *It is important to consider all nutrient sources—including fortified foods—to avoid exceeding the Tolerable Upper Intake Level (UL), which can be harmful.*

References (see more)

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7

Chapter 7: Digestion

Chapter 4: Digestion

7.1. The Organization of the Human Body

7.2. Digestive System Overview

7.3. Digestion

7.4. Nutrient Absorption and Delivery

7.5. Metabolism

7.6. Digestive Health and Disorders

7.1

The Organization of the Human Body

4.1 The Organization of the Human Body

The human body and the food we eat, like all matter on earth, are made up of atoms, the basic unit of a chemical element. These atoms combine to form molecules and then bind together to make bigger macromolecules. In living organisms, the macromolecules are organized into cells, the smallest and most basic form of life. The human body is comprised of trillions of cells, each is a compact and efficient form of life—self-sufficient, yet interdependent upon the other cells within your body to supply its needs.

Although the cell is the most basic unit of life, it is structurally and functionally complex. A cell can be compared to a miniature organism, containing tiny organs called organelles. Organelles are built from macromolecules bonded together and each has a specific role.

A typical human cell includes:

- The nucleus, which holds genetic material (DNA)
- Mitochondria, which generate energy
- Ribosomes, which produce proteins
- The endoplasmic reticulum, which packages and transports materials
- The Golgi apparatus, which processes and distributes macromolecules
- Lysosomes and peroxisomes, which break down macromolecules and destroy foreign substances

All organelles are suspended in the cytoplasm and surrounded by a plasma membrane, which separates the cell from its environment.

Single-celled organisms can function on their own. In contrast, cells in multicellular organisms, like humans, rely on each other and are organized into levels that perform specialized functions and support life processes.

Cells
Cells are the basic structural and functional units of life. Examples include red blood cells, which transport oxygen, and nerve cells, which transmit electrical signals.

Figure 4.1 A human cell. Photo by Bingbongboing under CC BY-SA 4.0 license with edits.

Tissues
Tissues are groups of similar cells that work together to perform specific functions. The four main types of human tissue are:

- Connective tissue, which supports and connects body parts
- Epithelial tissue, which covers surfaces and lines organs
- Muscle tissue, which enables movement and provides support
- Nervous tissue, which receives and transmits signals

Organs
Organs are made of two or more tissue types that work together to perform specific functions, such as the brain, liver, stomach, and heart.

Organ Systems
Organ systems are groups of organs that work together to carry out complex functions. Examples include the digestive system and nervous system. The human body has eleven organ systems (see Table 1).

Organism
An organism is a complete living being capable of performing all necessary biological processes for survival.

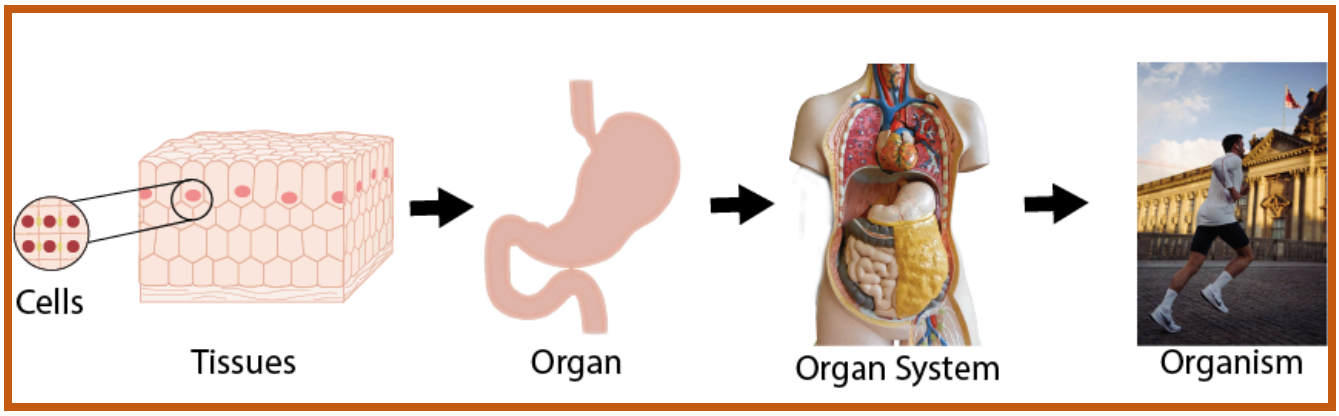


Figure 4.2: Cells are organized to form tissues, organs, systems, and whole organisms. Cell image created by Ap. Tissue Photo by Cancer Research UK / Wikimedia Commons under CC BY-SA 4.0 license with edits. Organ Photo by Cancer Research UK / Wikimedia Commons under CC BY-SA 4.0 license with edits. Organ System by Beat Ruest under CC BY-SA 4.0 license with ideas. Organism Photo by Florian Kurrasch on Unsplash.

Organ System	Organ Components	Major Function
Cardiovascular/Circulatory	Heart, blood/lymph, vessels, blood, lymph	Transport nutrients and waste products
Digestive	Mouth, esophagus, stomach, intestines	Digestion and absorption
Endocrine	All glands (pituitary, adrenal, thyroid, pancreas)	Produce and release hormones
Immune/Lymphatic	White blood cells, lymphatic tissue, marrow	Defend against foreign invaders
Integumentary	Skin, nails, sweat glands	Covers and protects the body; body temperature control
Muscular	Skeletal, smooth, and cardiac muscle	Body movement and structure
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

Table 1: The major organ systems of the human body

Key Takeaways

- *The human body is organized hierarchically, starting from atoms that form molecules, which in turn build cells—the smallest unit of life.*

- *The cell is a complex structure containing tiny "organs" called organelles, each with a specific function.*
- *In multicellular organisms, cells are organized into a tiered system: cells form tissues, tissues form organs, and organs work together in organ systems.*
- *There are four main types of tissue: connective, epithelial, muscle, and nervous tissue.*
- *The human body has eleven major organ systems, such as the digestive and nervous systems, which perform all the complex functions necessary for survival.*

References (see below)

7.2

Digestive System Overview

4.2 Digestive System Overview

The digestive system is one of the eleven major organ systems in the human body and has four main functions: ingestion, digestion, absorption, and waste excretion. The food we eat must be broken down so nutrients can be absorbed and waste can be eliminated.

Organs of the Digestive System

The **gastrointestinal tract** (also known as the **GI tract**, alimentary canal, digestive tract, or the gut) is a hollow tube-shaped organ about 30 feet long that runs through the body. The digestive system includes the **mouth**, **pharynx**, **esophagus**, **stomach**, **small intestine**, and **large intestine**, which ends at the **rectum** and **anus**. It also includes four supporting organs: **salivary glands**, **liver**, **gallbladder**, and **pancreas** (see Figure 4.3).

The inside of the GI tract is called the **lumen**, which is lined with a mucosal layer called the **mucosa**. Surrounding the tract are layers of connective tissue and smooth muscle that aid in digestion, provide protection and support, and supply nutrients to the mucosa.

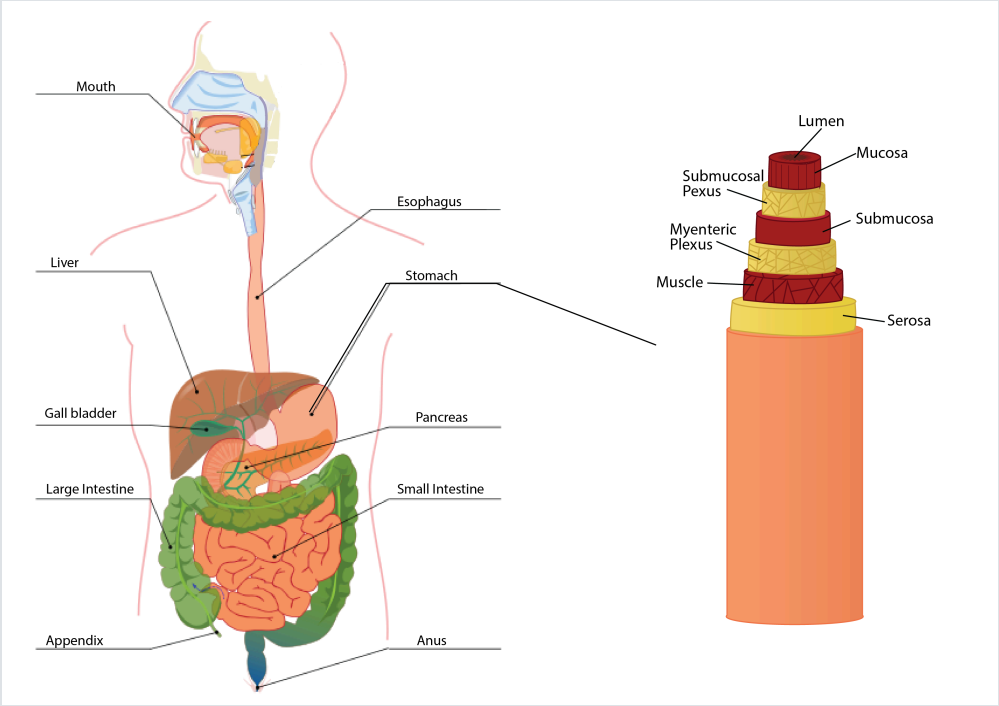


Figure 4.3: The digestive tract organs and close up of the layers of the intestinal tract wall. Created by Ap.

Chemical and Mechanical Digestion

Once you eat, your digestive system breaks food down into smaller components using **mechanical** and **chemical** processes. Mechanical digestion physically breaks food into smaller pieces, while **chemical digestion** uses enzymes in digestive secretions to break chemical bonds within nutrients so they become small enough to absorb (see Table 2). These digestive secretions come from the **salivary glands**, **stomach**, **pancreas**, and **small intestine**.

Chemical Secretions	Function	Secreted From
Enzymes		
Amylases (salivary, pancreatic)	Digests starch into smaller carbohydrate molecules	Salivary Glands and pancreas
Proteases (pepsin, trypsin, chymotrypsin)	Digests long protein chains into shorter fragments by breaking the peptide bonds	Stomach (pepsin) and pancreas (trypsin, chymotrypsin)
Lipases (lingual, gastric, and pancreatic)	Digests fats into glycerol and fatty acids	Mouth, stomach, and pancreas
Hormones		
Gastrin	Stimulates the stomach to release gastric acid	Stomach and duodenum
Secretin	Stimulates the secretion of pancreatic juice and enzymes	Small intestine
Cholecystokinin (CCK)	Stimulates the release of bile from the gallbladder and pancreatic enzymes	Small intestine
Other Secretions		
Saliva	Moistens mouth and food, eases swallowing, contains salivary amylase	Salivary glands
Mucus	Lubricates and coats the mucosa to protect it from digestive damage	Stomach, small and large intestines
Hydrochloric Acid (HCl)	An acid that lowers the pH in the stomach leading to the denaturation of proteins. It also activates pepsin which starts protein digestion by breaking the peptide bonds	Stomach

Bile	Emulsifies fat in the small intestine allowing for absorption	Liver (stored in the gallbladder)
Bicarbonate	An alkaline or basic substance that helps to neutralize stomach acid protecting the small intestine. This neutrality allows pancreatic enzymes to function	Pancreas (secreted into small intestine)

Table 2: The enzymes, hormones and digestive juices used in chemical digestion[2-10]

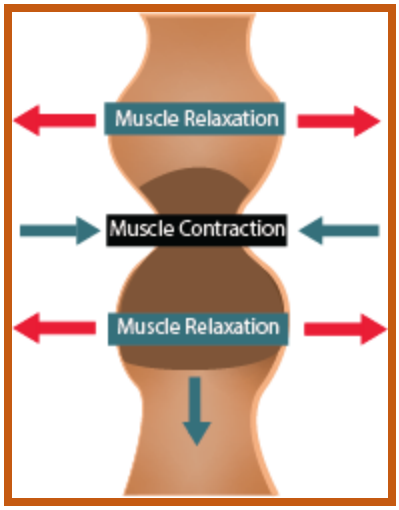


Figure 4.4: Peristalsis is rhythmic waves of muscle contraction and relaxation that moves the food through the digestive tract. Created by Ap.

Mechanical digestion includes chewing, crushing, and grinding food, followed by moving it through the GI tract using muscle contractions called **peristalsis** and **segmentation**. **Peristalsis** involves involuntary waves of smooth muscle contractions that mix food with digestive secretions and push it forward (see Figure 4.4). In contrast, **segmentation** moves food back and forth to enhance mixing. Once food is broken into smaller nutrient particles, they can be absorbed and used by cells for energy or to build and repair tissues.

Key Takeaways

- *The digestive system has for primary functions: ingestion, digestion, absorption, and waste excretion.*
- *The digestive system is composed of the gastrointestinal tract—a 30-foot-long hollow tube— and for supporting organs: the salivary glands, liver, gallbladder, and pancreas.*
- *Digestion occurs through two main processes: mechanical digestion physically breaks down food, and chemical digestion uses enzymes and hormones to break chemical bonds.*
- *Muscle contractions, specifically peristalsis and segmentation, are responsible for moving and mixing food throughout the GI tract.*

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7.3

Digestion

4.3 Digestion

Digestion actually begins even before you take a bite. When you are hungry and smell freshly baked pizza or see a plate of warm chocolate chip cookies, your mouth starts to salivate. The sight and smell of food signal your brain that it is time to eat. This triggers the release of saliva and other digestive juices, preparing your body to start digesting food.

From the Mouth to the Stomach

The Mouth

Ingestion is the first step of digestion and involves taking food into the mouth (see Figure 4.5). While it may seem simple, ingestion includes smelling food, thinking about food, and the involuntary release of **saliva** to prepare for eating. As food enters the mouth, enzymes like **salivary amylase** begin breaking down carbohydrates. At the same time, chewing (mastication) crushes and grinds large food particles into smaller pieces.

The Pharynx and Esophagus

The **pharynx** is responsible for swallowing. The process starts intentionally because you consciously push food back toward the throat with your tongue. After that, swallowing becomes involuntary and cannot be stopped once it begins. As you swallow, the **bolus** of chewed food moves from the mouth through the **pharynx** and into the muscular tube called the **esophagus**. While passing through the **pharynx**, a small flap called the **epiglottis** closes to keep food from entering the trachea, which connects the larynx to the lungs. **Peristaltic** contractions in the **esophagus** then push the food down toward the stomach. At the junction between the **esophagus** and stomach, a **sphincter** muscle stays closed until the **bolus** arrives. The pressure from the **bolus** signals the lower esophageal **sphincter** (see Figure 4.6) to relax and open, allowing food to enter the stomach. Solid food usually takes four to eight seconds to travel down the **esophagus**, while liquids take about one second.

From the Stomach to the Small Intestine

The Stomach

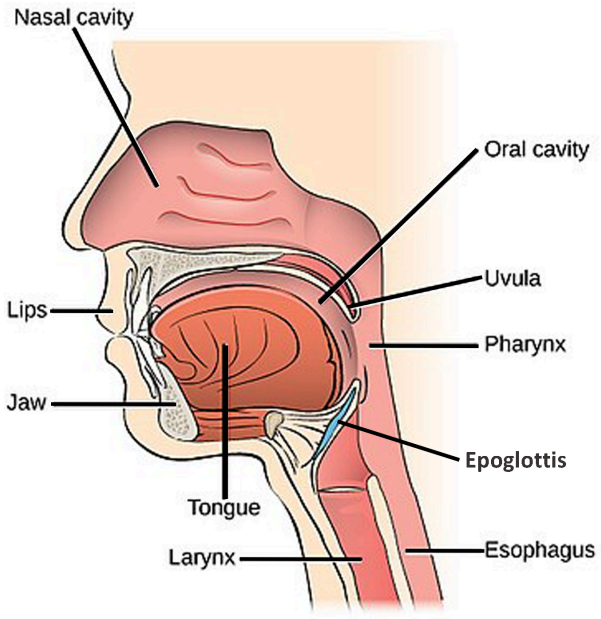


Figure 4.5: The digestive tract from the mouth to the esophagus. Image created by CNX OpenStax with CC BY 4.0 license with edits.

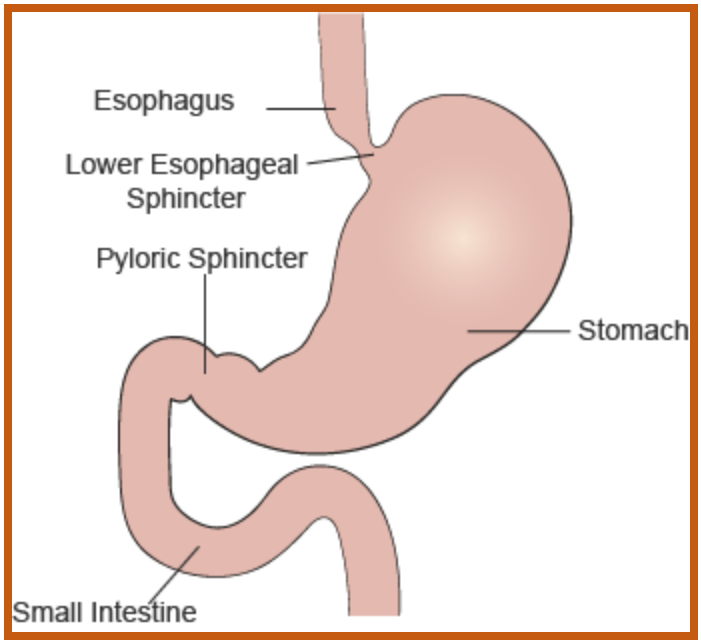


Figure 4.6: Placement of the lower esophageal and pyloric sphincters. Image is by Cancer Research UK / Wikimedia Commons with CC BY-SA 4.0 license with edits.

When food enters the stomach, a highly muscular organ, powerful peristaltic contractions help mash, pulverize, and churn food into chyme. **Chyme** is a semiliquid mass of partially digested food that also contains gastric juices secreted by cells in the stomach. Included in these gastric juices is **hydrochloric acid** (HCl) which activates the enzyme **pepsin**, also secreted by the cells in the stomach.[2] Pepsin chemically breaks down food into smaller molecules. The length of time food spends in the stomach varies by the macronutrient (carbohydrates, proteins, and lipids) composition of the meal. A high-fat, high-protein, or high-fiber meal takes longer to break down than one rich in simple carbohydrates. It usually takes a few hours after a meal to

empty the stomach contents completely. The chyme will leave the stomach passing through the **pyloric sphincter** (see Figure 4.6), a smooth muscle junction between the bottom of the stomach and the duodenum of the small intestine.

Small Intestine

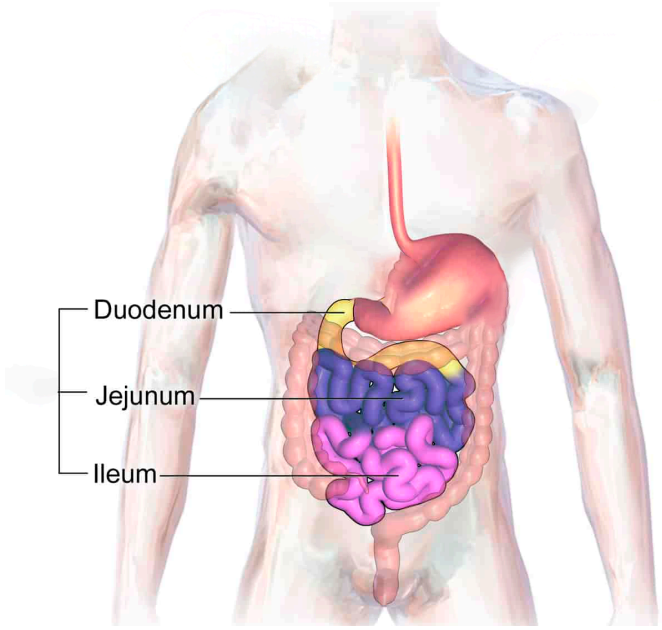


Figure 4.7 The small intestine is divided into three parts: the duodenum, jejunum, and ileum. Image provided by Blausen.com from the "Medical gallery of Blausen Medical 2014" under CC BY 3.0 license with edits.

The **small intestine** is about 20 feet long and 1 inch in diameter.11 It has three parts: the **duodenum**, **jejunum**, and **ileum**. When **chyme** enters the **duodenum** (the first segment), the **pancreas** and **gallbladder** release juices that help digest food. Within the first 25 centimeters of the **duodenum**, most food components are broken down into their simplest forms: **amino acids** (from proteins), **monosaccharides** (from carbohydrates), and **emulsified fatty acids** (from lipids).

The next step, nutrient absorption, mainly occurs in the **jejunum** and **ileum**. The **small intestine** is designed to maximize absorption, with a surface area over 200 square meters — about the size of a tennis court. This large surface area results from folds in its lining (see Figure 4.8), which are covered with thousands of **villi**, tiny finger-like projections. Each **villus** has even smaller **microvilli** on its surface, further increasing the area for absorption. Inside each **villus** are blood capillaries and lymph vessels that carry absorbed nutrients throughout the body.

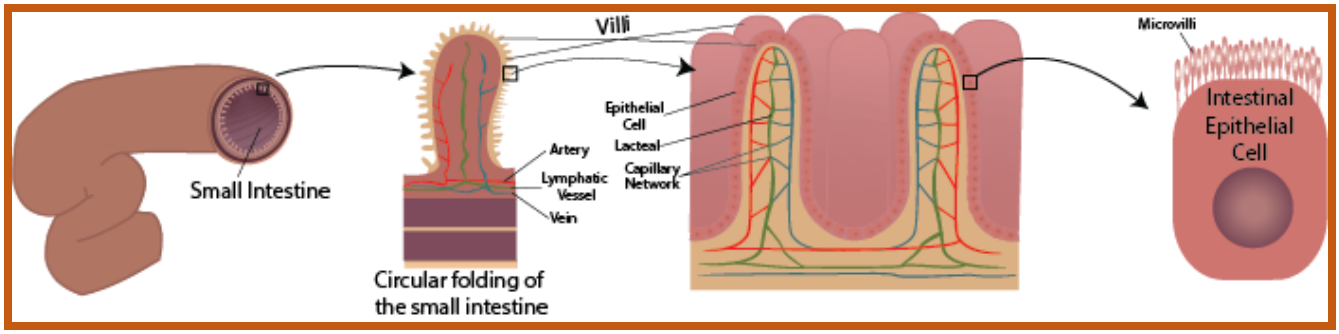


Figure 4.8: The intestinal folding, villi, and microvilli all increase the surface area of the small intestine to optimize nutrient absorption and is often called the brush border. Created by Ap.

From the Small Intestine to the Large Intestine

The process of digestion is fairly efficient. Any food that is still incompletely broken down (usually less than ten percent of food consumed) and the food's indigestible fiber content moves from the small intestine to the large intestine through the **ileocecal valve**, a connecting sphincter. The large intestine is about 5 feet long 3 inches in diameter and it consists of the colon, rectum and anus.[11]

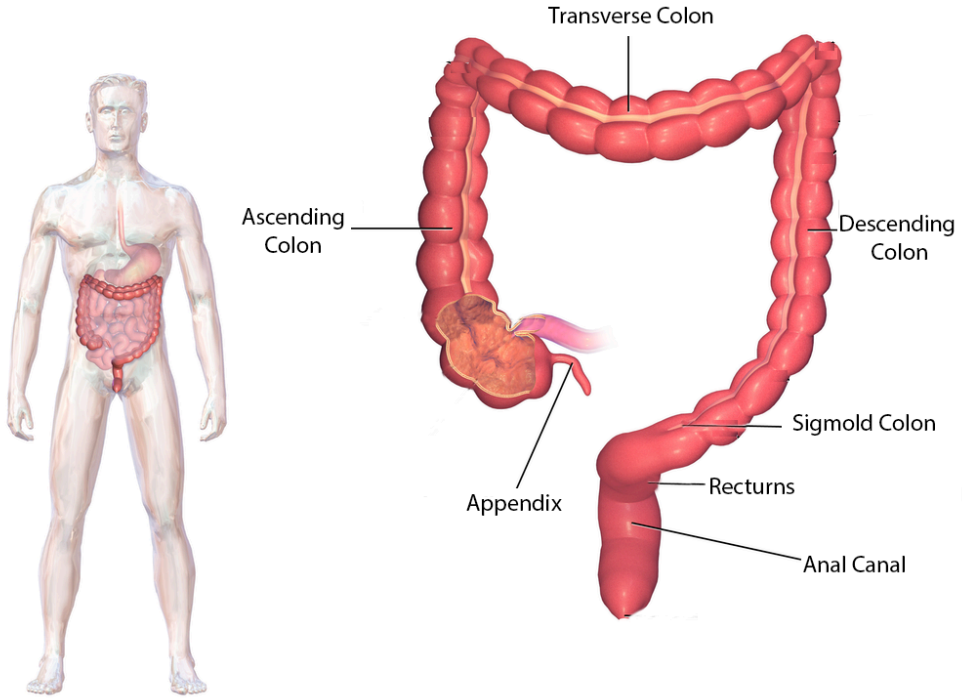


Figure 4.9 Diagram of the large intestine. Image by Blausen.com staff (2014). "Medical gallery of Blausen Medical 2014". WikiJournal of Medicine 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436 under CC BY-SA 3.0 license with edits.

The main task of the large intestine is to reabsorb water. Remember, water is present not only in solid foods, but also the stomach releases a few hundred milliliters of gastric juices and the pancreas adds approximately another 500 milliliters during the digestion of the meal. For the body to conserve water, it is important that the water be reabsorbed. In the large intestine, no further chemical or mechanical breakdown of food takes place, unless it is accomplished by the bacteria that inhabit this portion of the digestive tract. The number of bacteria residing in the large intestine is estimated to be greater than 100 trillion, which is more than the total number of cells in the human body (10 trillion). This may seem rather unpleasant, but the great majority of bacteria in the large intestine are harmless and most are even beneficial.

From the Large Intestine to Elimination

After a few hours in the stomach, plus three to six hours in the small intestine, and about sixteen hours in the large intestine, the digestive process enters step four, which is the elimination of indigestible food as feces. Feces contain indigestible food and gut bacteria (almost 50 percent of the content is bacteria). It is stored in the rectum until it is expelled through the anus via defecation or elimination.

Accessory Organs: Salivary Glands, Liver, Gallbladder and Pancreas

Although the food we eat does not pass through the salivary glands, liver, gallbladder, or the pancreas these supporting or accessory organs are still critical to the digestive process.

The **salivary glands,** found in your mouth, start the digestive process by releasing saliva, a watery fluid that helps to soften the food that you eat and makes it easier to swallow. Saliva contains water, electrolytes, enzymes (including salivary amylase which starts to break down carbohydrates) and mucus.

The **liver** is one of the largest organs of the body. It assists in digestion by making 600 to 1,000 milliliters of **bile** each day.[12]Once made, the bile is collected, concentrated, and stored in the **gallbladder**. The gallbladder can hold 30 to 60 milliliters of bile at one time.

The presence of food in the stomach and small intestine stimulates the release of the hormone cholecystokinin (CCK) by the small intestine which then prompts the release of bile from the gallbladder into the duodenum.[7] The bile emulsifies or surrounds the fat allowing for the movement of fats in the watery environment of the small intestine.[12] Through the emulsification process, large fat globules are separated into smaller droplets or particles making it more available for digestion by the lipase enzymes.[13,14]

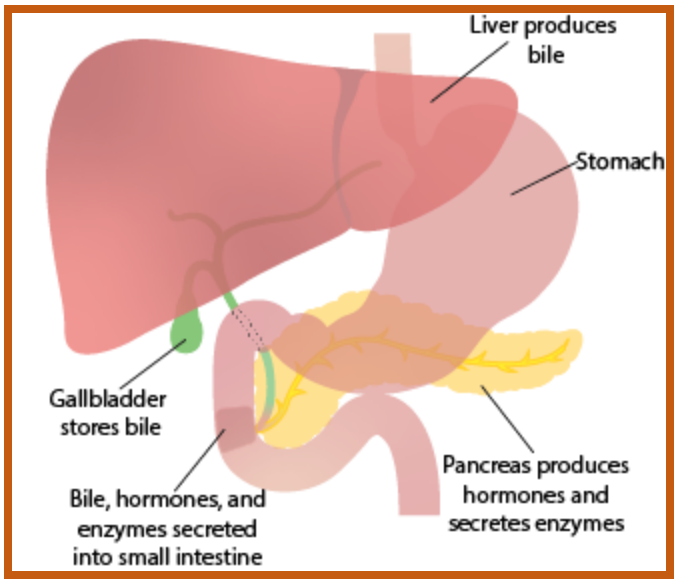


Figure 4.10 Accessory organs: liver, gallbladder, and pancreas assist with digestion. Image by Cancer Research UK / Wikimedia Commons under CC BY-SA 4.0 license with edits.

The **pancreas** secretes up to 1,500 milliliters per day of pancreatic juice through a duct into the duodenum of the small intestine. This fluid consists mostly of water, but it also contains bicarbonate and digestive enzymes. **Bicarbonate**, neutralizes the acidity of the stomach-derived chyme, raising the pH and making the small intestine environment more basic or neutral.[10] The neutral environment is needed for the **pancreatic enzymes** to function properly. These enzymes, released by the pancreas, help to further break down proteins, carbohydrates, and lipids (see Table 2 above in section 4.2 for further details on the digestive juices and enzymes).

Key Takeaways

- *Digestion begins even before you eat, with the sight and smell of food triggering the release of saliva and other digestive juices.*
- *Food travels from the mouth, where chewing and enzymes begin the breakdown, to the stomach, where it's mashed into semi-liquid call chyme.*

- *The small intestine is where the majority of nutrient breakdown and absorption occurs, thanks to a massive surface area provided by folds, villi, and microvilli.*
- *The large intestine's main function is to reabsorb water and serves as home to a vast population of beneficial bacteria.*
- *Accessory organs like the pancreas, liver, and gallbladder are crucial; they release essential substances like bile to break down fats and bicarbonate to neutralize stomach acid.*

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7.4

Nutrient Absorption and Delivery

4.4 Nutrient Absorption and Delivery

When the digestive system has broken down food to its nutrient components the body eagerly awaits absorption and delivery. For the nutrients to be used by the body cells they have to first leave the GI tract being absorbed through the intestinal wall and then delivered to one of the body's two transport systems: the circulatory (blood) or lymphatic systems. The choice of which system is used mainly depends on whether the nutrient is water or fat-soluble. Those nutrients that are water-soluble, such as glucose and amino acids are transported from the small intestine to the liver through the body's network of blood vessels and veins. Lipids and other fat-soluble nutrients are transported through the lymphatic system, before ever entering the blood.

Types of Absorption

Once the digested nutrients reach the small intestine they are absorbed by one of three methods: passive diffusion, facilitated diffusion, or active transport (see Figure 4.11). In **passive diffusion**, nutrients are moved across the intestinal cell membrane due to the concentration gradient that exists. This means that there is a difference in the number or amount of particles found on each side of the membrane. One side is higher or has more particles than the other side. For example, when the concentration is greater (more particles) in the GI tract than inside the intestinal cell (less particles), the nutrients freely, without needing energy or a transporter, move across the cell membrane. Similarly, in **facilitated diffusion** the nutrients are absorbed by moving from high to low concentration without needing energy. However, in facilitated diffusion a dedicated protein is needed to carry the nutrient across the cell membrane. In contrast, **active transport**, moves digested nutrients from a low to a high concentration requiring both energy and a protein carrier to move the nutrients across the cell membrane.

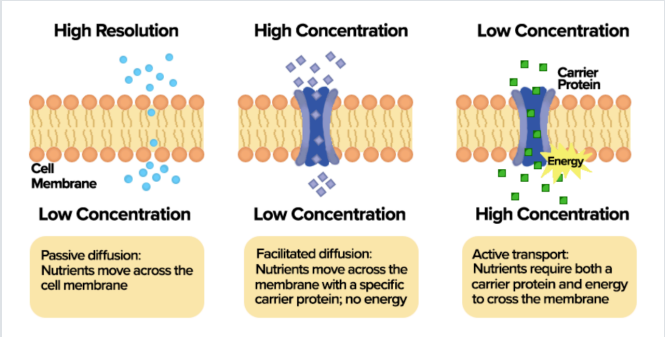


Figure 4.11: The three different small intestine absorption methods: passive diffusion, facilitated diffusion, and active transport. Created by AP and edited by AW.

The Circulatory System

The circulatory system, also known as the **cardiovascular system**, moves blood throughout the body (see Figure 4.12). Blood carries nutrients and oxygen to organs and tissues and removes carbon dioxide and other wastes. This system includes the **heart**, **blood**, and **blood vessels**. The **heart** pumps the blood, which acts as a transportation fluid. The network of blood vessels includes **arteries**, **veins**, and **capillaries**. **Arteries** carry blood away from the heart, while **veins** carry blood back to the heart.

Water-soluble nutrients absorbed in the **small intestine** mostly travel to the **liver** through the **hepatic portal vein**. The **liver** helps manage these nutrients by storing them, converting them to different forms, or releasing them into circulation to supply the rest of the body.

From the **liver**, nutrients move through the **inferior vena cava** to the **heart**. The heart pumps this nutrient-rich blood first to the **lungs** to pick up oxygen, then to all body cells. As **arteries** branch and get smaller, they become **capillaries**, the smallest blood vessels. **Capillaries** allow for the exchange of oxygen, nutrients, and wastes between blood and body tissues.15 The slow blood flow in **capillaries** gives cells enough time to absorb nutrients and remove wastes.

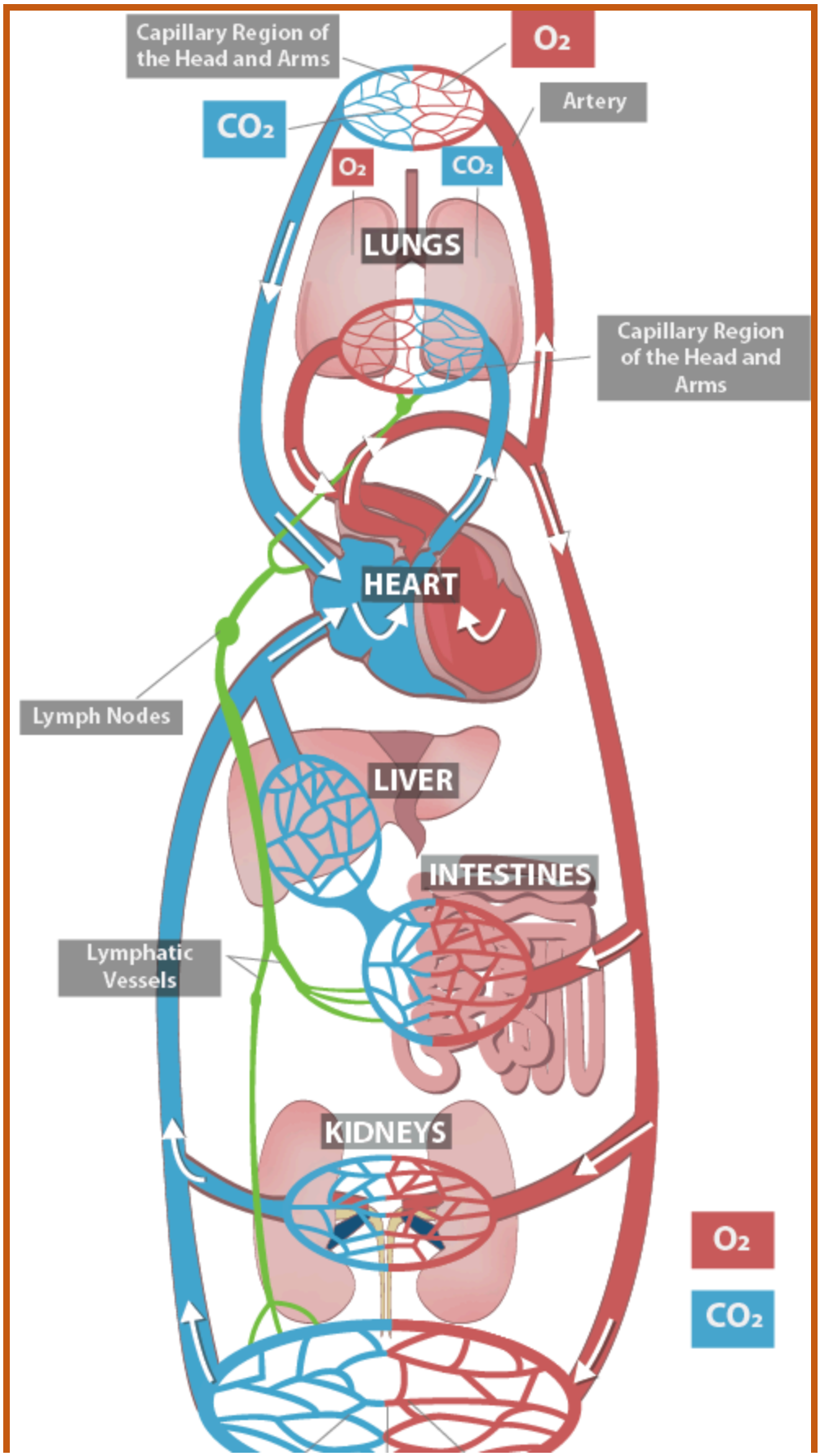
The Lymphatic or Immune System

Think of the **lymphatic** system as the body's drainage system. It consists of tubes, vessels, and other lymphatic organs that transport a fluid called **lymph**. Lymph is made up of whatever needs to be drained or moved from one place in the body to another. The lymphatic system has three main functions. First, it returns excess fluid from the tissues to the blood. Next, it defends the body against attacking microorganisms and disease. Finally, and most important in our discussion of digestion, it transports most fats and fat-soluble vitamins before they enter into the blood stream.

The process of absorption of these fat-soluble nutrients is similar to other nutrients except that the fat-soluble nutrients are packaged into fat transporters and pulled into lacteals and not into the blood capillaries. The **lacteals** are tiny lymph vessels which are also found in the middle of each small intestine villi (see Figure 4.13). The fat transporter or package is absorbed through the wall of the villi and enters into the lacteal. The lymphatic vessels then move or transport these fat transporters containing the fat-soluble nutrients and connect with the bloodstream near the heart (see Figure 4.12). So these nutrients enter the general circulation of the blood prior to passing through the liver.

Waste Removal

After digestion, any of the nutrients or other food material not absorbed into the body, such as fiber, will be eliminated through the feces. Waste products also accumulate inside the body and must be removed such as carbon dioxide, minerals, and nitrogen-containing materials. For example, after the breakdown of protein, urea, a nitrogen-containing waste product, must


Capillary Region of the Head and Arms
O2
Artery
CO2
O2
CO2
LUNGS
Capillary Region of the Head and Arms
HEART
Lymph Nodes
LIVER
INTESTINES
Lymphatic Vessels
KIDNEYS
O2
CO2



be eliminated. Through the circulatory system, the waste is picked up from the cells and excreted from the body through the lungs (carbon dioxide) or the skin. However, the kidney plays the main role in this waste elimination by filtering water and other waste materials from the blood and then concentrating the waste in the urine and excreting it out of the body.

Figure 4.12: Blood circulation through the body. Red color indicates blood is rich in oxygen and blue is for blood that carries carbon dioxide. The green vessel represents the lymphatic vessels. Created by AP.

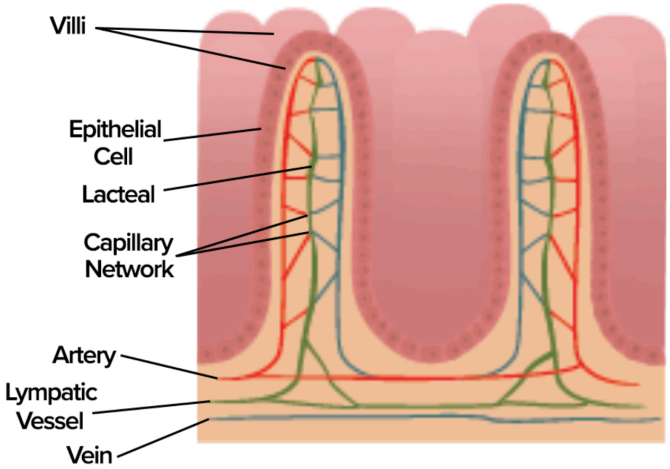


Figure 4.13: Villi containing both blood and lymph vessels for nutrient absorption. Created by AP.

Key Takeaways

- *Nutrients are absorbed through the intestinal wall and are delivered to the body's cells by either the circulatory system or the lymphatic system.*
- *The three absorption methods are passive diffusion, facilitated diffusion, and active transport, which differ based on whether they require a protein carrier or energy.*
- *Water-soluble nutrients are absorbed into the bloodstream and travel directly to the liver for processing before distributed throughout the body.*
- *Fat-soluble nutrients are absorbed into tiny lymph vessels called lacteal and transported by the lymphatic system, bypassing the liver before entering the bloodstream.*
- *The circulatory system uses the heart, blood, and blood vessels to transport nutrients and oxygen, while also removing waste.*
- *The lymphatic acts as the body's drainage system, transporting fat-soluble nutrients and defending against disease.*

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7.5

Metabolism

4.5 Metabolism

The organ systems of the body require fuel and building blocks to perform the many functions of the body. Once our food is digested and absorbed, the blood transports the nutrients to the cells where they are used in processes of metabolism. **Metabolism** is defined as the sum of all chemical reactions required to support life. Some of these reactions help us break down and release energy from carbohydrates, fats, proteins, and alcohol. Others allow us to build and make new substances. A group of chemical reactions in the body that progresses as a sequence from start to finish is called a **metabolic pathway**.

All the pathways that take place in the body can either be categorized as **catabolism**, the process of breaking down materials, or **anabolism**, the process of building larger materials from smaller components. Catabolic processes release energy and anabolic processes consume energy.

Catabolism and Energy Production

Each of the macronutrients, glucose, fatty acids, and amino acids, can be catabolized or broken down to release energy. Although these macronutrients do contain low energy bonds, they are not very useful to the cell in this form. As a result, they must undergo **cellular respiration** which is a process that transforms the food macronutrient energy into cellular energy.[16] This cellular energy is called **adenosine triphosphate (ATP)** and it contains very high energy bonds which when broken down and released can be used to perform cellular work such as active transport, muscle contractions, growth, and repair of tissues. All organisms from bacteria to humans use ATP as their main energy source.[16]

In cellular respiration, glucose, fatty acids, and proteins are converted into carbon dioxide, water, and ATP when oxygen is present (see Figure 4.14). First the macronutrients are broken down to form acetyl-CoA, a two-carbon molecule. Next, each acetyl-CoA enters the **citric acid cycle**, a multi-step circular pathway which produces ATP, carbon dioxide (CO^2), and high energy electrons (e-). These electrons are carried by molecules into the inner membrane of the mitochondria in preparation for the next stage, the **electron transport chain**. In this metabolic pathway, energy is released in the form of ATP as electrons are sequentially transferred between multiple proteins. At the same time, oxygen combines with electrons and hydrogen to form water.

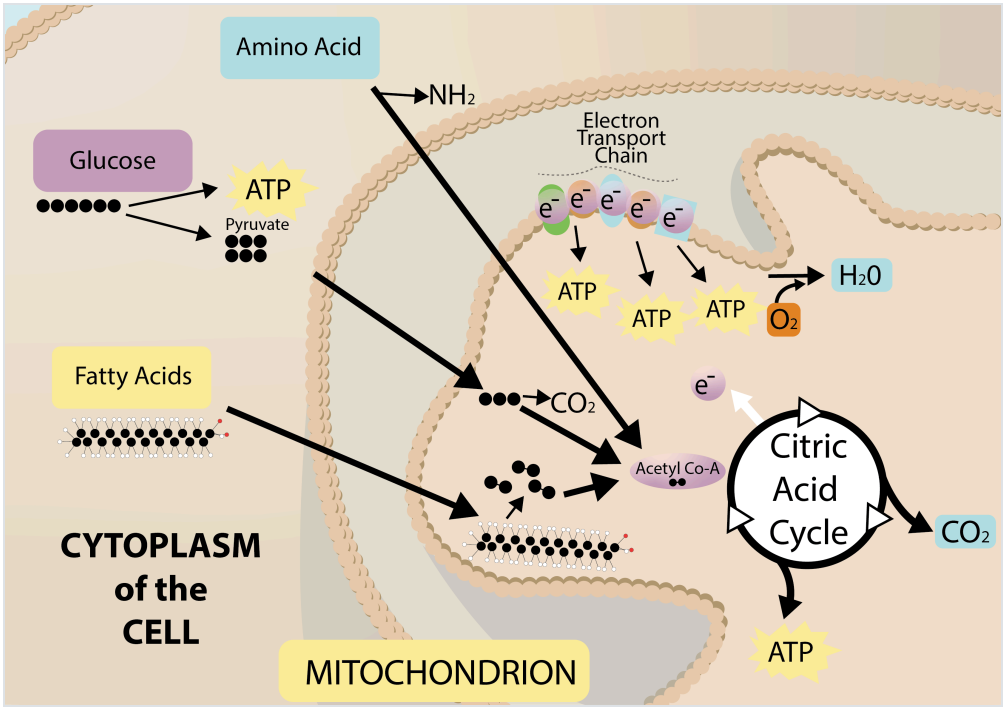


Figure 4.14: In the presence of oxygen, cellular respiration converts glucose, fatty acids, and amino acids into ATP or energy, carbon dioxide, and water. Created by AP.

Anabolism and Building

The energy released by catabolic pathways powers anabolic pathways in the building of macromolecules, cells, and tissues. Anabolic pathways are required to build new tissue, such as muscle, after prolonged exercise or the remodeling of bone tissue, a process involving both catabolic and anabolic pathways. Anabolic pathways also build energy-storage molecules, such as glycogen, the glucose-storage molecule. The glucose, fatty acids, and amino acids not being used for energy can be diverted and used as building blocks for these anabolic pathways.

Key Takeaways

- *Metabolism is the sum of all chemical reactions that support life and can be divided into two types of pathways: catabolism and anabolism.*
- *Catabolism is the process of breaking down substances, which releases energy.*
- *Anabolism is the process of building new, larger substances, which consumes energy.*
- *Through a process called cellular respiration, the body breaks down macronutrients to create a usable form of cellular energy call ATP.*
- *ATP is the main energy source used by cells to perform various functions, including active transport, muscle contractions, and tissue repair.*

References (see below)

7.6

Digestive Health and Disorders

4.6 Digestive Health and Disorders

The GI tract allows us to obtain the nutrients that we need on a day to day basis. It also helps to protect the body from disease-causing organisms and contaminants. Although the GI tract usually works well, there are times that problems arise causing uncomfortable symptoms and problems. Some of these concerns are minor and infrequent, such as heartburn, while others can be more serious such as stomach ulcers and colon cancer.

Food Allergies

Paying attention to the way individuals react to various foods is essential in determining what foods may specifically affect a person adversely. Food allergies are one of the many ways in which different body make-ups affect nutritional concerns. It is estimated that 3.5 to 4 percent of the overall population have food allergies; however, there are likely many more people who say they have food allergies than actually do.17 This is because food sensitivity or intolerance is different from a medically-determined food allergy. When someone has a food allergy, the immune system mistakenly attacks a fragment of digested food (usually the protein component of a food), such as the protein component of peanuts, as if it were a threat and antibodies are produced. Doctors sometimes test for food allergies by using skin-prick tests or blood tests to look for the presence of antibodies. However, these types of tests are not always reliable as they can sometimes yield a false positive result. By far, the most valuable tests for determining a food allergy is the Double Blind Placebo Controlled Food Challenge (DBPCFC), which involves administering the food orally and then denoting the signs and symptoms of the allergic response. In contrast, a food sensitivity or intolerance does not stimulate the immune system, but can cause similar symptoms as a food allergy.

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: severe headaches or migraines, a tingling mouth, swelling tongue and/or throat, difficulty breathing, hives, stomach cramps, diarrhea, vomiting, drop in blood pressure, loss of consciousness, and death.

There are no clear treatments for food allergies. Epinephrine is used to control severe reactions. The only certain way to avoid allergic reactions to food is to avoid the foods that cause them. Beyond avoidance, this can mean reading food labels

carefully, or even calling manufacturers for product information. Most food allergies are caused by these nine foods: milk, eggs, peanuts, tree nuts, fish, shellfish, wheat (this is different than celiac disease), sesame and soy.

Celiac Disease

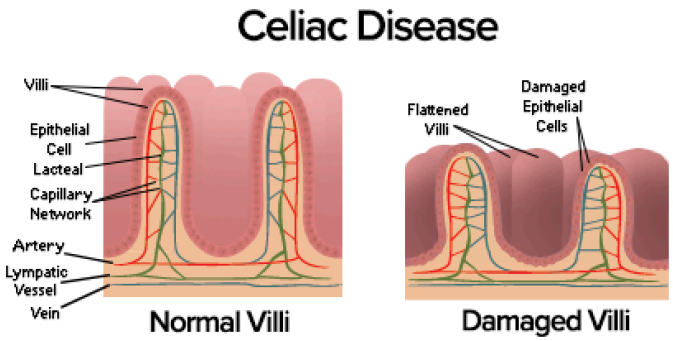


Figure 4.15: Normal intestinal villi compared to damaged villi resulting from celiac disease. Created by AP.

Celiac disease is an autoimmune digestive disorder, not a food allergy, which damages the small intestine. It is caused by an abnormal immune reaction of the small intestine cells to a type of protein, called gluten found in wheat, barley, and rye. 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 4.16). Villi destruction is what causes many of the symptoms of celiac disease. The destruction of the absorptive surface of the small intestine 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.

Celiac disease develops in about 1 in 100 people worldwide.[18] It is an inherited disorder meaning it can only develop in individuals that have particular genes. These genes are common and are found in about one-third of the population; however, only 3 percent of individuals with the genes will ever develop celiac. This suggests that there are other factors, possibly environmental, that influence the initiation of the disease.[18]

Symptoms can vary and range from mild to severe and can include pale, foul-smelling, fatty, loose stools, abdominal pain, bloating, gas, diarrhea, constipation, weight loss and in children, a failure to grow and thrive. The symptoms can appear in infancy or much later in life, even at age seventy. Celiac disease is not always diagnosed because the symptoms may be mild. A large number of people have what is referred to as “silent” or “latent” celiac disease.

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. However, the damage to the small intestine villi can only be detected with a biopsy, a procedure that removes a portion of the tissue from the damaged organ.

Fortunately, celiac disease can be treated. Once diagnosed, a person follows a gluten-free diet for life. This requires dedication and careful detective work to seek out and avoid foods with hidden gluten. For those who are sensitive to gluten, it is good to know that corn, millet, buckwheat, rice, quinoa, and oats do not contain the proteins that make gluten. However, some people who have celiac disease also may have an adverse response to products containing oats. This is most likely the result of cross-contamination of grains during harvest, storage, packaging, and processing. After eliminating gluten from the diet, the tissues of the small intestine rapidly repair themselves and usually heal in less than six months.

Gastroesophageal Reflux Disease

Gastroesophageal reflux disease (GERD) is a persistent form of acid reflux that occurs more than two times per week. Acid reflux, also known as **heartburn**, occurs when the acidic contents of the stomach leak backward into the esophagus and

cause irritation (see Figure 4.15). It is estimated that GERD affects 20 percent of the US population.[19]

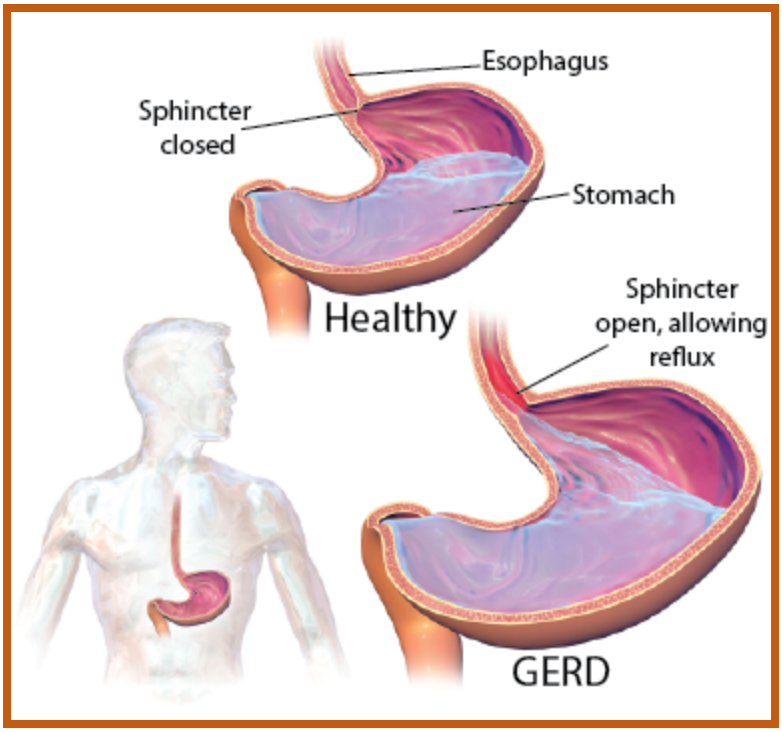


Figure 4.16: GERD takes place when the lower esophageal sphincter opens allowing stomach contents to flow back into the esophagus. Image by Andrewmeyerson under CC BY-SA 4.0 license with edits.

The most common GERD symptom is regular heartburn, but people with GERD may also experience regurgitation (flow of the stomach's acidic contents into the mouth), pain in the upper abdomen or chest region, frequent coughing, respiratory problems, and painful or trouble swallowing.

GERD occurs when the lower esophageal sphincter (see Figure 4.15) weakens or relaxes when it should not, allowing the stomach contents to flow back into the esophagus. Certain things can weaken or relax the sphincter including increased pressure on the abdomen such as in obesity or pregnancy, certain medications, and smoking.

The first approach to GERD treatment is dietary and lifestyle modifications. Recommendations suggest that you reduce weight if you are overweight or obese, avoid foods that worsen GERD symptoms, eat smaller meals, stop smoking, and remain upright for at least three hours after a meal. Foods that worsen GERD symptoms are foods that increase stomach acidity or slow gastric emptying and include chocolate, garlic, greasy (higher fat) or spicy foods, peppermint, caffeine, alcohol, and tomato-based foods.

There are also many medications available to treat GERD, including antacids, histamine (H2) blockers, and proton-pump inhibitors. When these treatment approaches do not work, surgery may also be an option. The most common surgery involves reinforcing the sphincter that serves as a barrier between the stomach and esophagus.

Peptic ulcers

A **peptic ulcer** is an open sore that forms in the lining of the esophagus, stomach, or upper small intestine when the protective mucus layer has been reduced or damaged. The lining is then exposed to gastric acids leading to the ulcer. Specifically, long-term use of nonsteroidal anti-inflammatory drugs (NSAIDs) such as aspirin or ibuprofen may result in an ulcer as they decrease the protective mucus layer. Even more common, these ulcers are caused by the *H. pylori* bacteria which damages the mucous layer of the stomach and small intestine exposing the lining to damage.

Luckily, the *H. pylori bacteria* can easily be treated with antibiotics. The most common symptom of a peptic ulcer is a dull or burning pain in your stomach region. Signs of red blood in the stools or having black stools is an indication of a more serious ulcer that should be addressed with your doctor immediately.[20]

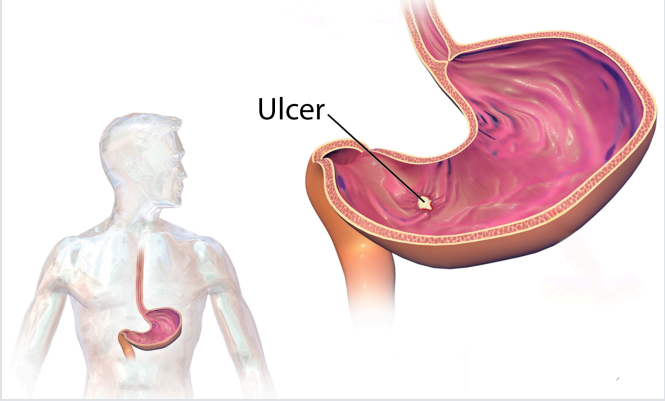


Figure 4.17: Peptic ulcers are sores that can occur in the lining of the esophagus, stomach, or upper small intestine. Image by Modificado de BruceBlaus under CC BY-SA 4.0 license with edits.

Gallstones

Gallstones are hard particles, like rocks, that form in the gallbladder and can range in size from a grain of sand to a golf ball.[21] A person may develop a single large gallstone, hundreds of tiny gallstones, or both. These stones can cause sudden pain in the upper right abdomen when the gallbladder contracts. They are formed by imbalances in the substances that make up bile such as cholesterol, bilirubin, and calcium. These substances accumulate in the gallbladder and can block bile from entering the small intestine which may lead to reduced fat absorption. Why these imbalances occur is unknown.

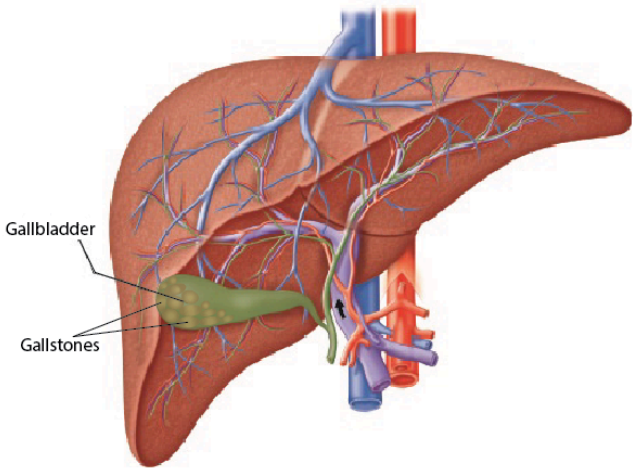


Figure 4.18: Gallstones found in the gallbladder can be painful and can block bile from entering the small intestine. Image by Cenveo under CC BY 4.0 license with edits.

Often gallstones are asymptomatic or do not cause pain and treatment is not necessary. However, when a person is having pain or other symptoms the typical treatment is surgery to remove the gallbladder. As the gallbladder is not an essential organ, a person can live normally without it. After surgery, the bile which is made in the liver will drip directly into the small intestine rather than being stored in the gallbladder.[21]

Irritable Bowel Syndrome

Irritable bowel syndrome (IBS) is a common disorder that affects the large intestine and is associated with a range of symptoms including abdominal pain, bloating or distension, gas, constipation, and diarrhea. Interestingly, IBS produces no permanent structural damage to the large intestine as often happens to patients who have more serious intestinal disorders such as celiac disease.

It is estimated that IBS affects between 7 and 15 percent of the population and is more prevalent in women than men.[22] The exact cause of IBS is not clearly understood, but it is thought to result from a combination of altered gut microbiota, hypersensitivity to intestinal pain (visceral hypersensitivity), changes in the GI motility, and low-grade inflammation.[23] There is no specific test available to diagnose IBS, so diagnosis is often a process of ruling out other conditions that have similar symptoms, such as celiac disease. These tests might include stool analysis, blood tests, x-rays, an endoscopy, or colonoscopy.

Symptoms of IBS significantly decrease a person's quality of life and as with GERD, the first treatment approaches for IBS are diet and lifestyle modifications with the goal to reduce common triggers. These triggers or stimuli are not always the same for all people with the condition. Large meals and foods high in fat and added sugars, or those that contain wheat, rye, barley, peppermint, and chocolate can intensify or bring about symptoms of IBS. Additionally, beverages containing caffeine or alcohol may worsen IBS. Stress and depression may compound the severity and frequency of IBS symptoms. 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 to exercise. There is also a fairly new, research-based dietary treatment that is gaining popularity due to its positive results called the low fermentable, oligo-, di-, mono-saccharides and polyol (FODMAP) diet. This diet is discussed in more detail below.

Finally, there are some medications, many of which can be purchased over-the-counter, to treat IBS and the resulting diarrhea or constipation. Sometimes antidepressants and drugs to relax the colon may also be prescribed.

FODMAP Diet

FODMAPs (fermentable oligosaccharides, disaccharides, monosaccharides, and polyols) are a group of highly fermentable but poorly absorbed short-chain carbohydrates and polyols found in foods.[24] Fermentation of these FODMAPs by the bacteria in your large intestine is completely normal and healthy; however, for people with IBS eating high FODMAP foods may trigger increased symptoms of excess gas, bloating, cramping, diarrhea and/or constipation.

The FODMAP diet is a two-part elimination diet that first restricts these highly fermentable short-chain carbohydrates and polyols (the FODMAPs) and then slowly reintroduces specific FODMAPs as tolerated.[25] In both randomized clinical trials and nonrandomized intervention studies, the FODMAP diet has been shown to significantly reduce the severity of IBS symptoms and increase quality of life.[26] These results are exciting and have given individuals with IBS an additional treatment option. However, even as the research shows promising results, a person should use caution before trying the diet as the research is still in its infancy and long-term results and physiological consequences are not known.[25] As this is a complicated diet to initiate and is highly restrictive and can lead to nutritional deficiencies, it should be initiated and supervised by a trained registered dietitian nutritionist or gastroenterologist.

Probiotics and Prebiotics

When we hear the word "bacteria" or "microorganism" we most likely think of disease. However, our bodies are full of bacteria. In fact, the bacteria in our bodies outnumber human cells by 10 to 1.[27] The large community of microorganisms found in the gut is called the **gut microbiota** or gut flora. Most of these microorganisms are found in the large intestine and are harmless or even beneficial to our health. For instance, they have many important functions including making certain vitamins, metabolizing nutrients, and stimulating immunity.[28,29]



Examples of fermented food containing probiotics- kimchi, red beets, apple cider vinegar, yogurt, sauerkraut, and cucumber pickles. Photo by little plant on Unsplash.

Bacteria can also be consumed to improve human health. Live microorganisms that provide health benefits when consumed in adequate amounts are called **probiotics**.[30] They can be found in supplements or food that has been prepared by bacteria fermentation. Some of these foods include yogurt, kefir, sauerkraut, tempeh, and kimchi. Probiotics contain many different types of microorganisms. The most common groups include Lactobacillus and Bifidobacterium and within each of these groups there are different species and each species has many different strains. [27]

Preliminary research has shown that probiotics can be helpful in digestive health by:

- Maintaining a desirable gut microbiota
- Protecting the GI tract from unwanted microorganisms or preventing their growth
- Assisting the gut microbiota in returning to normal levels after antibiotic use or disease
- Stimulating immune response [27]

Specifically, probiotics have been shown to be effective in preventing antibiotic-associated diarrhea and improving IBS symptoms.31,32 However, it is important to keep in mind that the research is still in its early stages. Not all probiotics are alike. Rather, they are strain specific and benefits cannot be generalized to other species or other strains of the same species.[33] For instance, just because one type of Lactobacillus provides a health benefit does not mean another type of Lactobacillus will have the same benefit. This large variety makes research and defining definitive effects difficult. Even for conditions that have been studied the most, it is still not known for sure which probiotics are most helpful, how much should be used, and who is most likely to benefit.27 So, before going out and buying probiotics, which can be expensive, an individual should use caution and make sure to research the type of probiotics that will most likely lead to the benefits they are seeking.



Probiotic supplements can contain different strains of Lactobacillus or Bifidobacterium and may benefit gut health. Photo by James Yarema on Unplash.

Non digestible food components that promote the growth of helpful bacteria in your gut are called **prebiotics**. Prebiotics include a range of different dietary fibers including fructooligosaccharides (such as inulin), and galactooligosaccharides. Understanding what food components may or may not work effectively as a prebiotic can be quite complicated to sort out. Rather than worrying about these details you can increase the prebiotics in your diet by eating more fruits, vegetables and whole grains. Specific food examples that are rich in prebiotics are bananas, onions, garlic, leeks, asparagus, artichokes, beans and whole-grain foods.

Foods that contain both probiotics (live heath promoting bacteria) and prebiotics (food for the bacteria) are referred to as synbiotics. Both supplements and specially designed food products are available that contain both probiotics and prebiotics. You can create your own symbiotic meal by eating a food with probiotics like yogurt with a food with prebiotics such as a banana.[34]

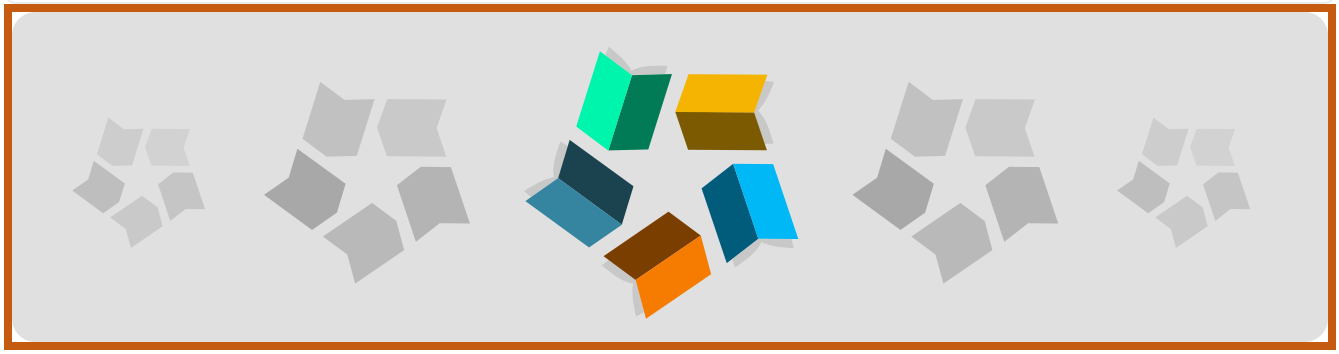
Key Takeaways

- *A food allergy is a serious immune system response to a food, which is different from a food sensitivity or intolerance.*
- *Celiac disease is an autoimmune disorder, not a food allergy, where gluten causes damage to the small intestine's villi, leading to nutrient malabsorption.*
- *Common digestive issues like Gastroesophageal Reflux Disease (GERD) and Irritable Bowel Syndrome (IBS) can often be managed through diet and lifestyle changes.*
- *Probiotics are live, beneficial microorganisms (found in food like yogurt) that help maintain a healthy gut, while prebiotics are non-digestible fibers that feed these bacteria.*

- *Other disorders include peptic ulcers (often caused by the H. pylori bacteria) and gallstones, which are hard particles that can form in the gallbladder.*

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8

Chapter 8: Carbohydrates

Chapter 5: Carbohydrates

Daniel, Shadrach, Meshach, Abednego appeared to do quite well physically eating pulse (KJV, Daniel 1: 15-16). The LDS Bible Dictionary defines pulse as: *The Hebrew word denotes seeds, and may include the grains of leguminous vegetables or any other edible seeds.*[1]

Carbohydrates are an important energy source for the body and the primary energy source for the central nervous system. They are found primarily in plants. Carbohydrates found in whole foods like vegetables, fruits, whole grains and unsweetened dairy foods promote good health. Sugars and other refined carbohydrates are not nutrient-dense food sources and should be limited in our food intake.

8.1. Types of Carbohydrates and Their Food Sources

8.2. Digestion, Absorption and Metabolism of Carbohydrates

8.3. Carbohydrate Regulation in the Body

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8.1

Types of Carbohydrates and Their Food Sources

5.1 Types of Carbohydrates and Their Food Sources

The name "carbohydrate" reflects the basic structural composition of carbohydrates; A carbohydrate contains carbon and water (carbo-hydrate). Plants make carbohydrates by absorbing energy from the sun to combine carbon dioxide from the air with water from the soil. Carbohydrates are broken down into two types, **simple** carbohydrates, and **complex** carbohydrates.

Simple Carbohydrates

The simple carbohydrates are commonly called "sugars" and are composed of two main groups, the **monosaccharides** and the **disaccharides**.

Monosaccharides

Monosaccharides consist of a single carbohydrate unit called a “saccharide” (saccharide is the Latin word for “sugar.”) There are three monosaccharides: glucose, galactose, and fructose.

Glucose: All organisms from bacteria to plants to animals use glucose as a fuel source to create energy. Under normal conditions, the brain and central nervous system are dependent on glucose as its energy source. Glucose as a monosaccharide is found in some fruits and honey. Although glucose by itself does not exist in large amounts in most food, it is a major component of other types of carbohydrates.

Galactose: The monosaccharide galactose differs from glucose in only one way. The difference is the position of one hydroxyl (−OH) group attached to a carbon atom (see Figure 5.2). This small structural alteration causes galactose to be less stable than glucose. As a result, the liver rapidly converts it to glucose. As a monosaccharide, there is very little galactose in our diet. Most of the galactose we consume is part of the disaccharide lactose, which is found in milk.

Fructose: Structurally, fructose is different from glucose or galactose because its ring contains only five carbons. However, it contains the same number of carbon, oxygen, and hydrogen, as glucose and galactose. Fructose in the liver may be used for

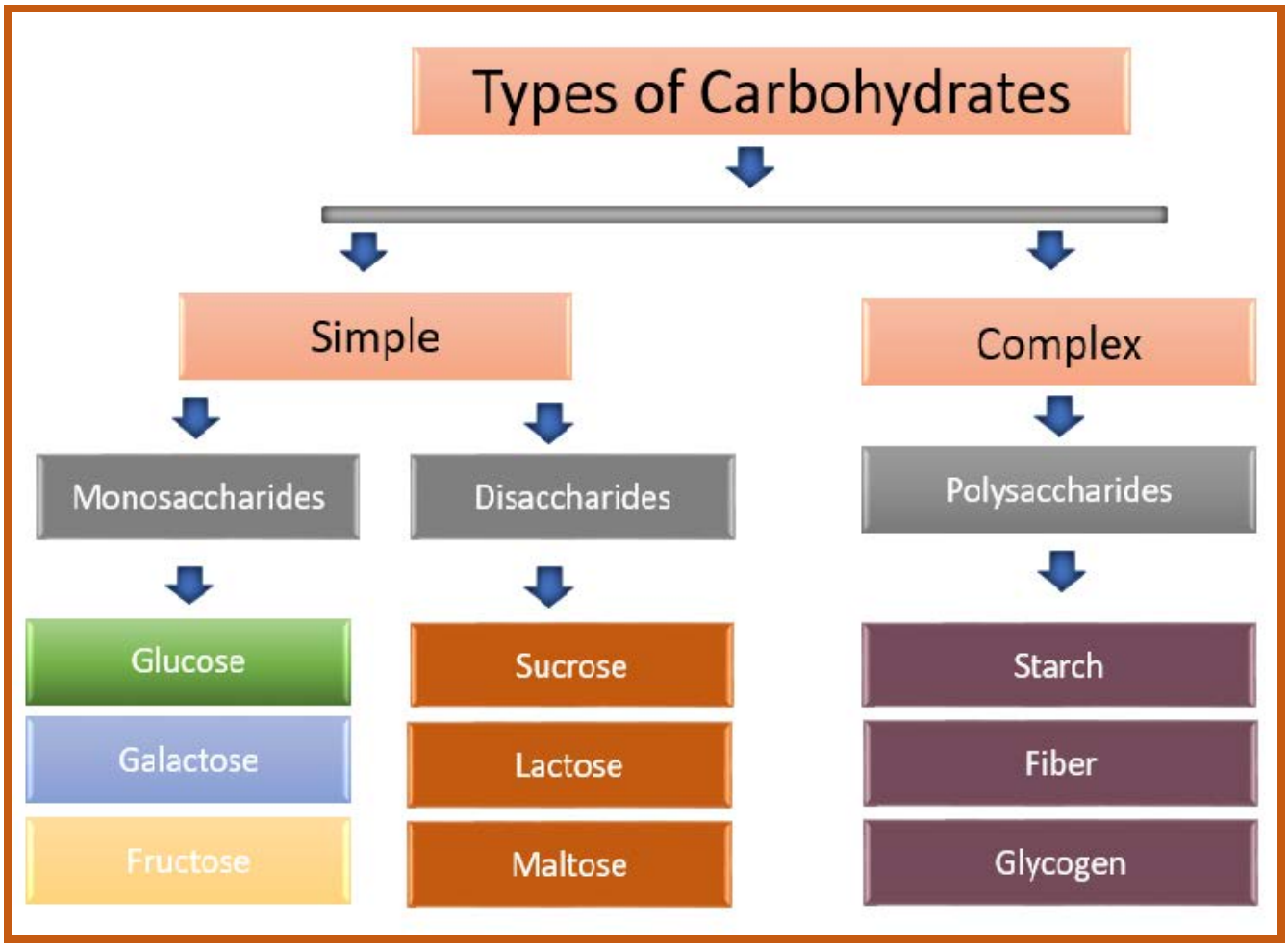


Figure 5.1: Overview of carbohydrates dividing the group into simple and complex, and further dividing simple carbohydrates into monosaccharides and disaccharides

energy, converted to glucose, or converted to fat. Like galactose, fructose is not typically used directly as an energy source for other body cells. Fructose is found in our food supply naturally in fruits, honey, and anything containing the disaccharide sucrose. The amount of fructose in the American food supply has increased over the last 30 years due to the growing use of the sweetener high fructose corn syrup and sucrose in beverages, bread, and many other products.

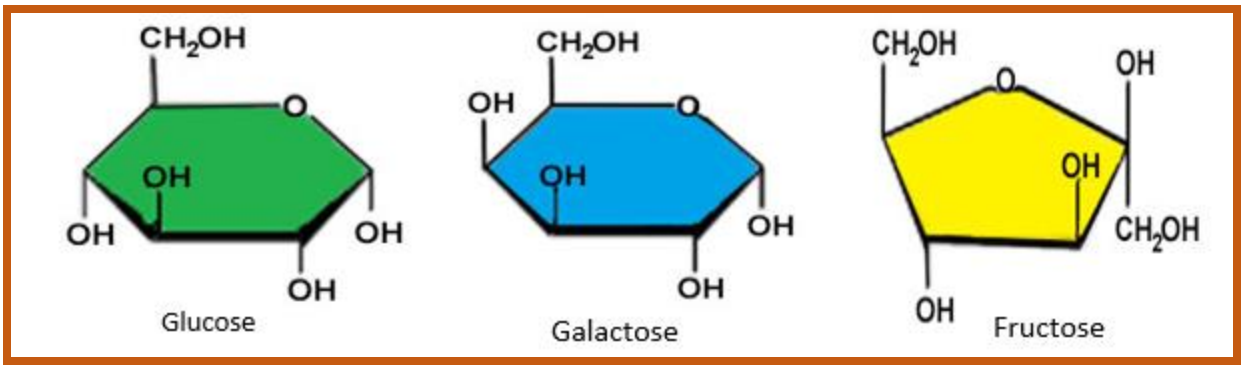


Figure 5.2: Structure of the monosaccharides

Disaccharides

Disaccharides are composed of two monosaccharides linked together. The three disaccharides are sucrose, lactose, and maltose. These disaccharides all contain at least one glucose molecule (see Figure 5.1).

Sucrose: Sucrose is composed of a glucose molecule and a fructose molecule bonded together. Sucrose, or table sugar, is made by extracting and purifying the sucrose from sugar beets and sugar cane. Sucrose may be found in some fruits and some vegetables, however, the majority of the sucrose that we consume is found in sweetened beverages and foods like cake, cookies, candy, energy drinks, and soda.

Lactose: Lactose is composed of a glucose molecule and a galactose molecule bonded together. Lactose is commonly known as milk sugar and is found in dairy products such as milk and yogurt.

Maltose: Maltose is composed of two glucose molecules bonded together. It is not commonly found in foods but is a common breakdown product of plant starches.

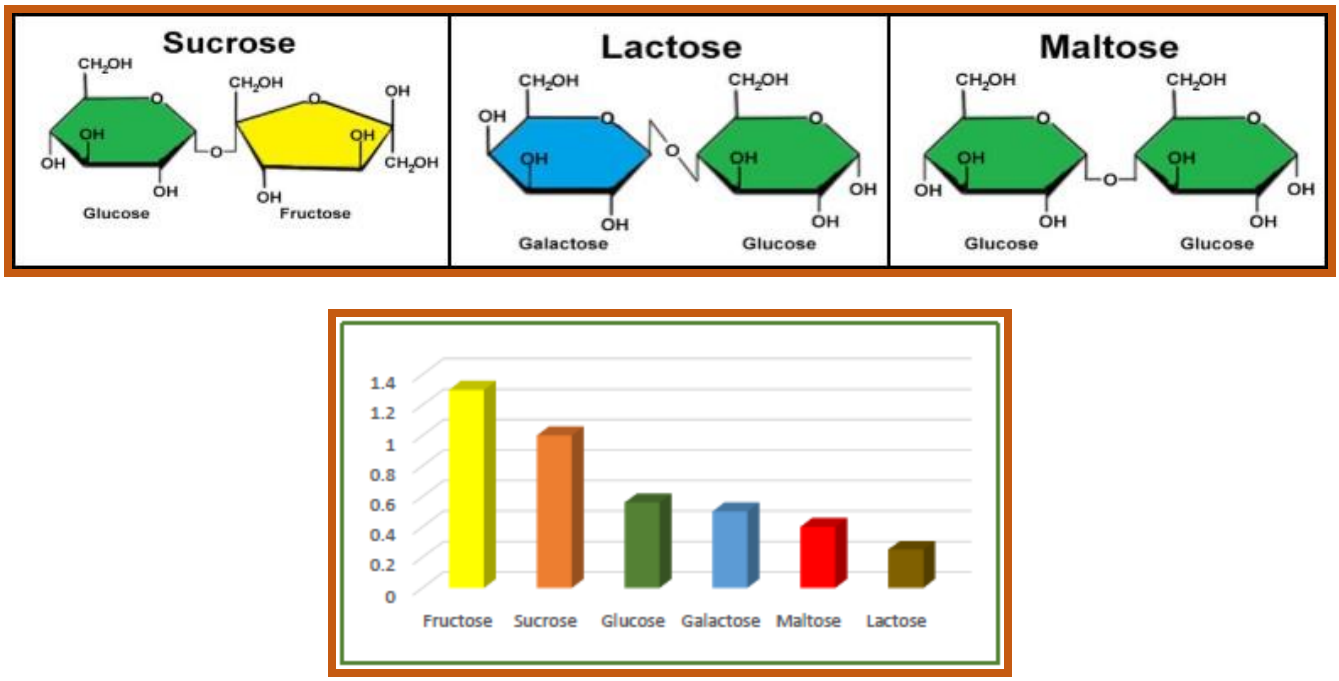


Figure 5.4: Relative sweetness of sugars. Data from Data take from McWillliams, Margaret Monosaccharides, Disaccharides and Sweeteners. In: Foods Experimental Perspectives. 5th ed. Upper Saddle River, NJ:Pearson/Prentice Hall;2005:151-177.

The monosaccharides and disaccharides have varying degrees of sweetness (see Figure 5.4). When the purified simple carbohydrates are added in the processing or preparation of foods, they are referred to as **added sugars**. These added sugars contribute additional calories to foods but provide no additional nutrients thereby diminishing the **nutrient-density** of food products.

Sugars added in this way are often referred to as **empty calories**. Currently, high fructose corn syrup is one of the most common added sugars used in the food industry in America. It is a liquid blend of the monosaccharides glucose and fructose. Its composition is similar to sucrose (50% glucose, 50% fructose) but the monosaccharides are not bonded together as they are in sucrose. The amount of fructose in high fructose corn syrup in soda can range from 40% to 65%.

Complex Carbohydrates

Complex carbohydrates are **polysaccharides**, long chains of monosaccharides that may be branched or not branched. There are two main groups of polysaccharides: **starches** and **fibers**.

Starches

Starch molecules are found in abundance in grains, legumes, and root vegetables, such as potatoes. **Amylose**, a plant starch, is a linear chain containing hundreds of glucose units. **Amylopectin**, another plant starch, is a branched chain containing thousands of glucose units. These large starch molecules are the energy storage for plants. Both amylose and amylopectin are found in starchy foods. Amylose, which is shorter and unbranched, is more abundant than amylopectin in foods (see Figure 5.5).

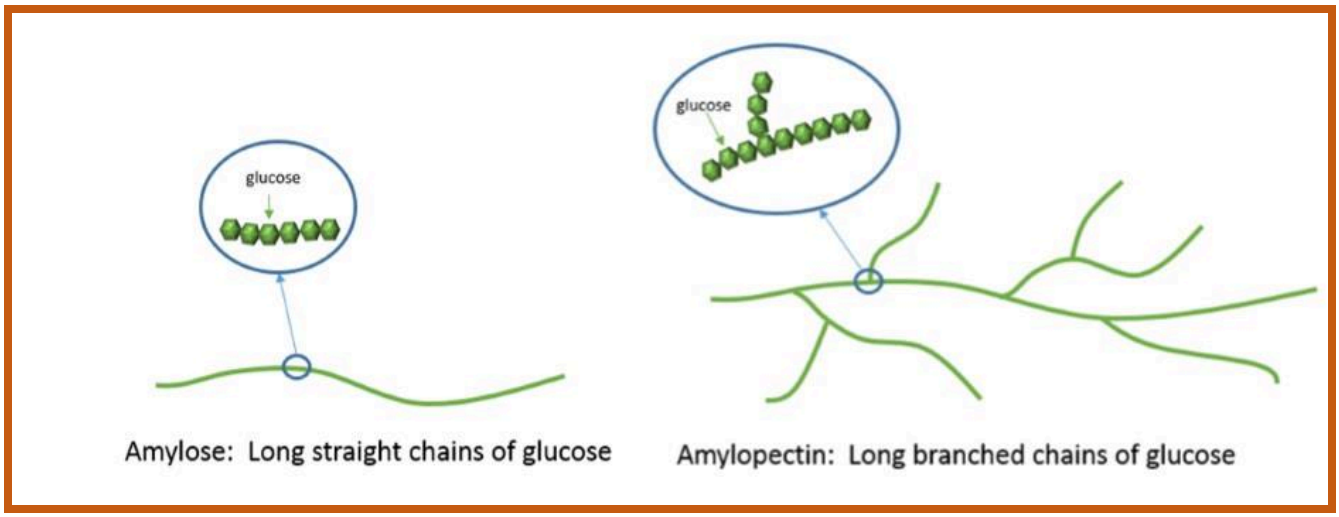


Figure 5.5: The starches amylose (straight) and amylopectin (branched)

Humans and animals can store glucose in the liver and muscle in the form of polysaccharide called **glycogen**. Glycogen is similar to amylopectin, but is more branched. The high degree of branching in glycogen allows it to break down quickly to glucose when energy is needed by cells in the body. During exercise, the amount of glycogen available throughout extended exertion becomes an important factor in performance.

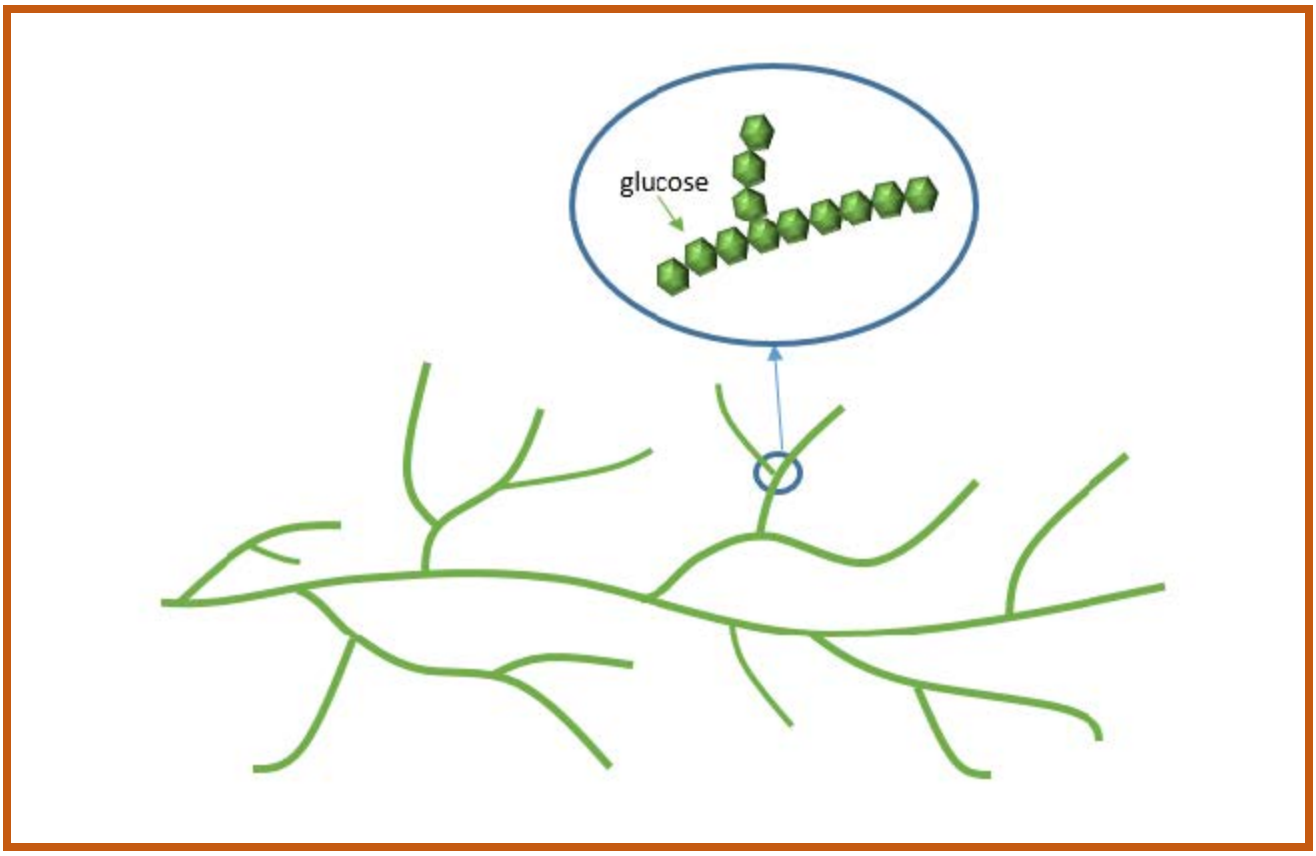


Figure 5.6: Glycogen: Long highly branched chains of glucose

Fiber

Most fibers are polysaccharides that are highly branched and cross-linked. Some examples of dietary fibers are **pectin**, **gums**, and **cellulose**. Humans do not produce the enzymes that can break the bonds in these compounds. However, bacteria in the large intestine (colon) contain the enzymes to break down some types of fiber. The digested fiber can then serve as an energy

source for the bacteria and for body cells. Fiber is very beneficial to human health in a number of different ways. Dietary fiber is important for colonic health and the maintenance of regular bowel movements. A growing body of evidence also suggests that fiber may play a role in preventing coronary heart disease, colorectal and other cancers, type 2 diabetes and obesity." Fiber is one of the nutrients considered to be inadequate in the diets of Americans.

Fiber is categorized as either **water-soluble** or **water-insoluble**. Inulin, pectin and guar gum are water-soluble fibers found abundantly in peas, dried beans, oats, barley, and rye. Good dietary sources of water-insoluble fibers like cellulose and lignin are found in brown rice, cracked wheat, flax, carrots and cabbage. As the name implies, soluble fibers dissolve in water and form a viscous gel-like substance. Insoluble fibers do not readily dissolve in water and do not form a gel-like substance. Insoluble fiber is sometimes referred to as "roughage." Insoluble fiber creates a structural matrix in the large intestine, and soluble fiber forms a gel.

Generally, soluble fibers are more easily accessible to bacterial enzymes in the large intestine and are broken down to a greater extent than insoluble fibers. The differences in their physical properties account for the varied health benefits that are associated with each type of fiber.



Fiber-rich foods including grains, vegetables, fruits, and nuts. Created by AP.

Soluble Fibers	Insoluble Fibers
Stool regularity (keeps things moving)	Stool regularity (keeps things moving)
Calorie control (helps you feel full)	Calorie control (helps you feel full)
Regulation of blood sugar levels	Lowest risk for diverticulosis & hemorrhoids
Reduced cholesterol levels	

Table 1: Positive effects of the different fiber types[3]

Fiber can also be discussed as **dietary fiber** or **functional fiber**. As it sounds, dietary fiber is fiber that comes naturally in the foods that are eaten. Functional fibers have been added to foods and

can also be beneficial to humans. Functional fibers may be extracted from plants and purified, or it can be synthetically made. Psyllium-seed husk acts as a functional fiber when it is added to products to increase fiber levels. Scientific studies show that consuming psyllium-seed husk can reduce blood-cholesterol levels. This health claim has been approved by the FDA. Total dietary fiber intake is the sum of dietary fiber and functional fiber consumed.[4]

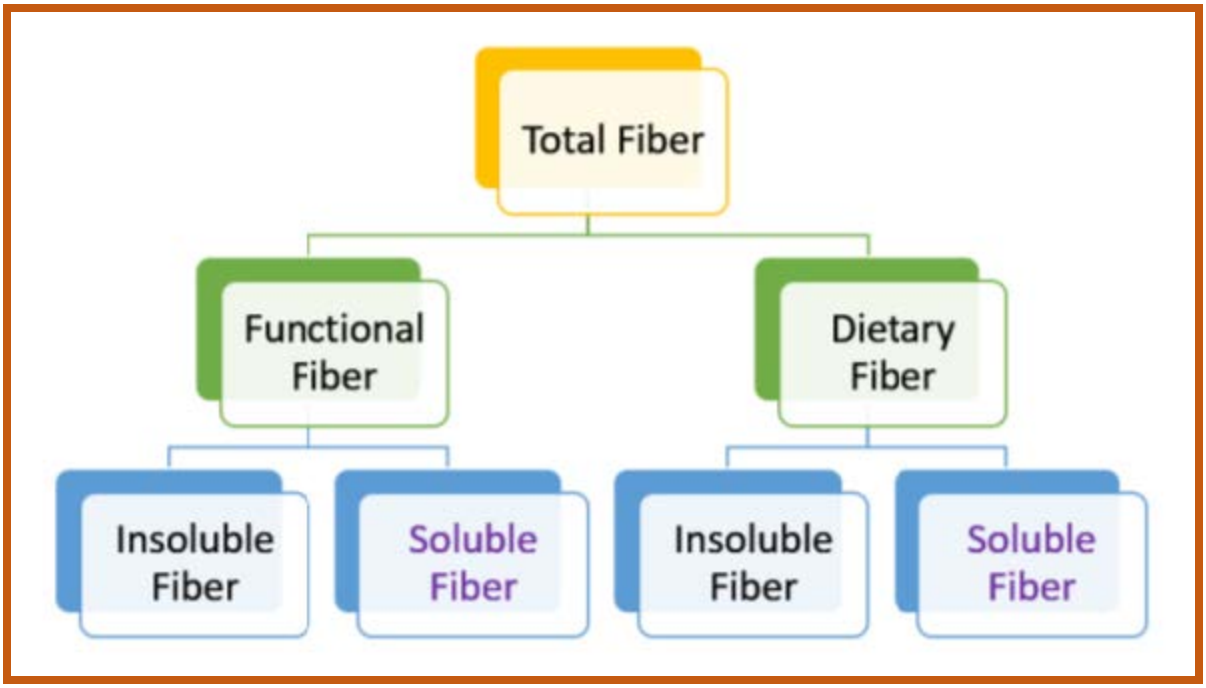


Figure 5.7: Fiber Categories

Refined Versus Unrefined Carbohydrates

In ancient times, whole grains were cracked open using quern stones (stones used for hand grinding). This required hours of hand labor. As technology slowly advanced, the quern stone was

modified and became the millstone. It was not until the advent of water wheels that human labor to produce flour out of whole grains was reduced. About 2,500 years ago, the Romans started milling flour by turning one millstone wheel against another stone that did not move. The turning was done by animals, slaves, and later by waterwheels.

Wheat was the grain of choice for many cultures, as it not only produced white flour but also contained gluten. Gluten is a substance that gives wheat bread its elasticity and lightness in texture. In America, Oliver Evans built the first flour mill, which was powered by a watermill. It used a series of elevators that moved grain through the mill, cleaning it first, then grinding and sifting it. Today, modern milling processes are faster and much more sophisticated, but work on the same basic principles. The process of milling breaks the hard outer bran coat of the wheat or other seeds. For example, white rice has also been refined from brown rice. The cracked seed can then be ground more finely into whole-wheat flour, or sifted in preparation to make refined wheat flour (white flour). In the refining process, the bran and germ are usually removed from the whole grain. The bran and germ are the nutrient dense parts of the grain containing the majority of the fiber, vitamins, minerals and healthy fat. In former times, the whitest flour was chosen to make bread for the wealthy, and the coarsest was given to the poor.

The fine texture, lighter color and blander taste of the flour of refined grains is preferred by most consumers over the coarser texture, darker color and richer flavor of whole grain flours. Equally important to the food industry is the removal of the fat and fiber that can contribute to rapid spoilage. Unfortunately, the over-use of refined grain flours has led to justified health concerns. In America in the early 1900s, several diseases stemming from vitamin and mineral deficiencies, such as pellagra (deficiency of niacin, B3), beriberi (deficiency of thiamin, B1), and anemia (iron deficiency), plagued many people. A public health campaign was initiated that required that all refined grain products be enriched. Enrichment is the adding back in of nutrients that are lost during processing, specifically the vitamins, thiamin, riboflavin and niacin and the mineral iron. In 1998

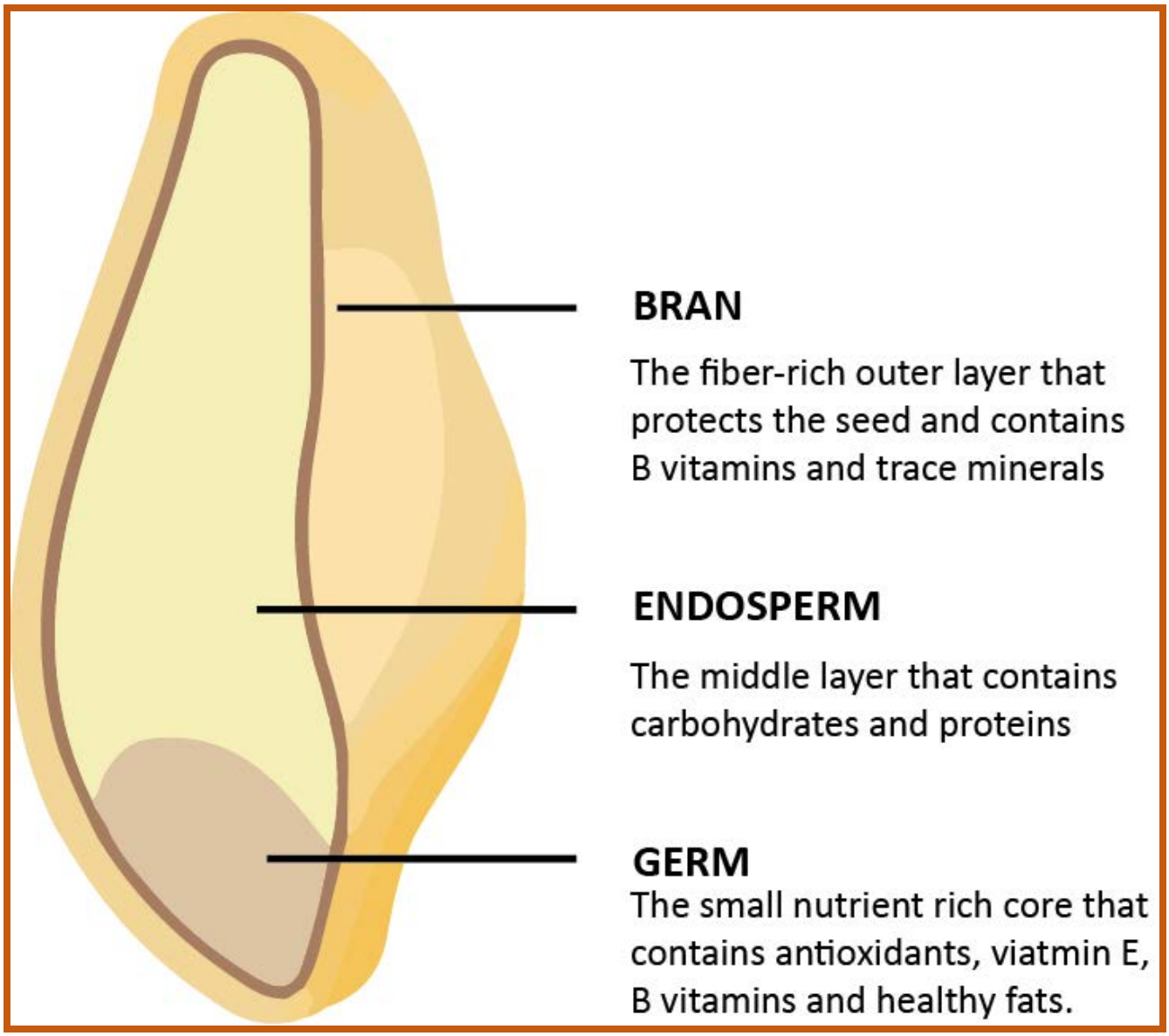


Figure 5.8: Components of a Whole Grain

the vitamin folate was added to the list of required nutrients. These changes have been beneficial but they do not compensate for the other nutrients lost in the refining process.

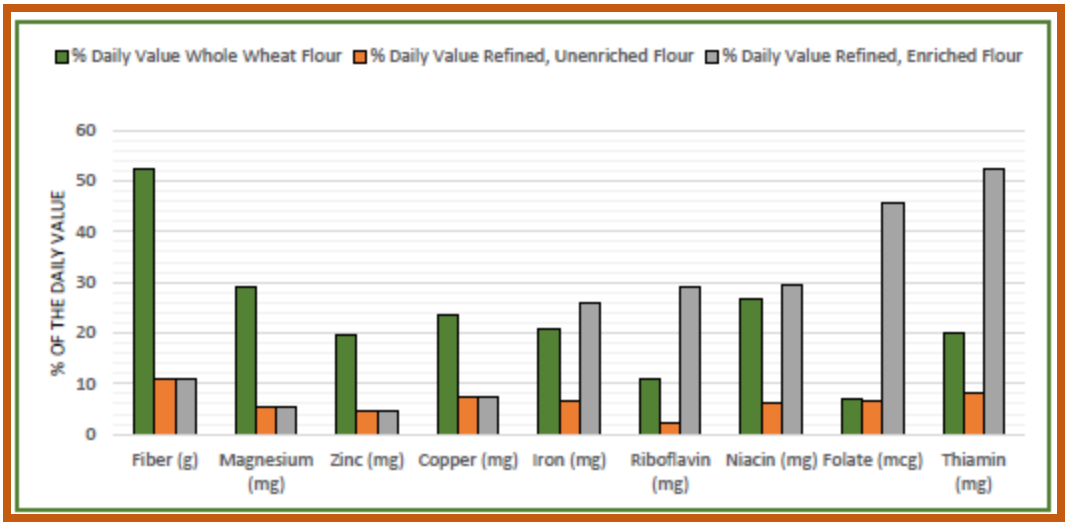


Figure 5.9: Effects of refinement and enrichment on nutrient content of wheat flour (100 gram serving)

The comparison of the nutrient composition of whole grains and refined grains in Figure 5.8 is clear evidence for the importance of choosing whole grains over refined grains when planning meals. The levels of riboflavin, niacin, and thiamin are clearly restored back into refined grains, but fiber, magnesium, zinc and copper remain reduced. A number of other nutrients and phytochemicals are lost in processing but are not reflected in this graph. The Dietary Guidelines for Americans recommend that at least half of our grain choices come from whole grains because the overwhelming scientific evidence supports the importance of eating whole grains over refined grains for optimal health. Regular consumption of whole grains has been associated with a reduction in coronary heart disease, cardiovascular disease, cancer, and diabetes.[5] It is important to minimize the consumption of refined grain foods which often have added fats and sugars, and instead choose nutrient-dense whole grain foods to help avoid chronic disease.

Key Takeaways

- *Carbohydrates are divided into two main types: simple carbohydrates (sugars like glucose and fructose) and complex carbohydrates (long chains of sugars like starches and fibers).*
- *Starches are the way plants store energy, while glycogen is the primary form of carbohydrate storage in the human body.*
- *Fiber is a complex carbohydrate that is not fully digestible by humans but is highly beneficial for health, promoting bowel regularity and reducing the risk of chronic diseases.*
- *Refined grains have been stripped of their bran and germ during processing, which removes most of their fiber and nutrients, while whole grains retain these components.*
- *The Dietary Guidelines for Americans recommend that at least half of our daily grain intake should come from whole grains due to their superior nutrient content.*

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8.2

Digestion, Absorption and Metabolism of Carbohydrates

5.2 Digestion, Absorption and Metabolism of Carbohydrates

The only carbohydrates that can be absorbed are monosaccharides such as glucose, fructose, and galactose. The goal of carbohydrate digestion is to break down the polysaccharides and disaccharides to these three monosaccharides.

From the Mouth to the Stomach

The **mechanical** and **chemical** digestion of carbohydrates begins in the mouth. Chewing, also known as mastication, crumbles the carbohydrate foods into smaller and smaller pieces. The salivary glands in the oral cavity secrete saliva that coats the food particles. Saliva contains the enzyme, **salivary amylase**. This enzyme breaks the bonds between the glucose units in starch. The salivary amylase breaks down amylose and amylopectin into smaller chains of glucose, called dextrins, and the disaccharide maltose. Only about five percent of starches are broken down in the mouth. When carbohydrates reach the stomach, no further significant chemical breakdown occurs because the amylase enzyme does not function in the acidic conditions of the stomach. However, the mechanical breakdown is ongoing—the strong peristaltic contractions of the stomach mix the carbohydrates into a more uniform mixture called chyme.

From the Stomach to the Small Intestine

The **chyme** (mixture of food and digestive juices) is gradually expelled into the upper part of the small intestine through the pyloric sphincter. Upon entry of the chyme into the duodenum, the pancreas releases pancreatic juice through a duct into the duodenum. This pancreatic juice contains the enzyme **pancreatic amylase** which resumes the breakdown of dextrins into shorter carbohydrate chains. Eventually, starch is broken down completely into maltose. Additionally, enzymes are secreted by the intestinal cells that line the villi (brush border) which continue the breakdown of the disaccharides lactose, maltose, and sucrose. The enzyme **sucrase** breaks sucrose into glucose and fructose molecules. Then the enzyme **Maltase** breaks the bond between the two glucose units of maltose. The enzyme **lactase** breaks the bond between galactose and glucose. Figure 4.10 shows the breakdown of lactose by lactase in the brush border of the small intestine. The process is similar for each of

the disaccharides. Once carbohydrates are chemically broken down into single sugar units (glucose, fructose or galactose) they are then transported into the intestinal cells. Glucose and galactose are moved into the cell via active transport; fructose is moved in via facilitated diffusion.

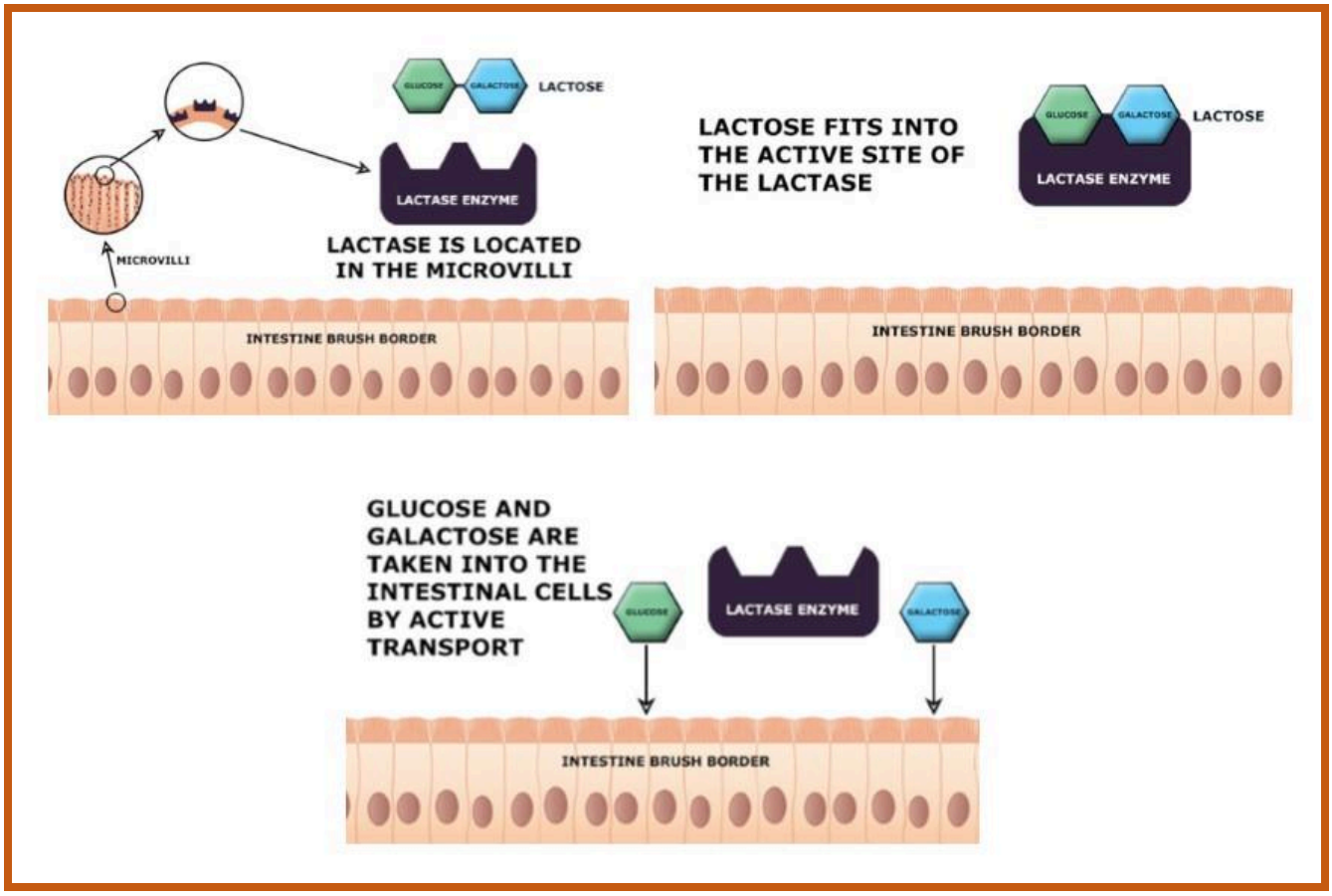


Figure 5.10: Three images showing the breakdown of lactose by lactase at the small intestine brush border. Provided by Debra Lowe.

When people do not have enough of the enzyme lactase, lactose is not sufficiently broken down resulting in a condition called **lactose intolerance**. The undigested lactose moves to the large intestine where bacteria are able to digest it. The bacterial digestion of lactose produces gasses which can lead to the symptoms of diarrhea, bloating, and abdominal cramps. Lactose intolerance usually occurs in adults and is more common in certain nationalities. In the United States, it is more common for African Americans, Hispanics/Latinos, Native Americans and Asian Americans to have lactose intolerance than those of European descent.[6] Most people with lactose intolerance can tolerate some amount of dairy products in their diet. Cheese is typically better tolerated because most of the lactose is removed when the milk is processed into the cheese. Yogurt is also better tolerated due to the bacterial action on the lactose in the yogurt. There are also products specially formulated for people that experience lactose intolerance. A commercially produced lactose-free milk has already had all the lactose broken down into glucose and galactose before it is sold in the store. The severity of the symptoms a person experiences depends on how much lactose is consumed and the degree of lactase deficiency.

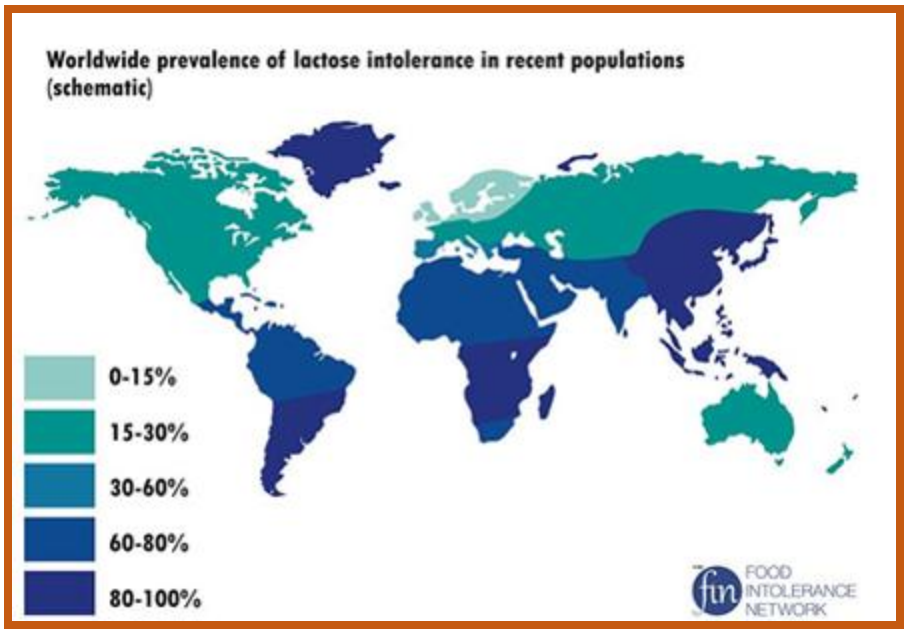


Figure 5.11: Worldwide incidence of lactose intolerance. Image by NmiPortal under CC BY-SA 3.0 license.

Absorption: Going into the Blood Stream

After the monosaccharides (glucose, fructose, and galactose) are absorbed, they move into the bloodstream and move directly to the liver via the portal vein where they are taken up by the liver cells. The liver cells can use small amounts of fructose for energy or convert it to glucose or fat. The fat can either be stored in the liver or transported out of the liver. Liver cells convert galactose to glucose. The liver closely regulates what happens to glucose. It can use some of the glucose to meet its energy needs; it can store the glucose as glycogen; it can convert the glucose to fat, or it can release the glucose into the blood- stream for use in other tissues. For example, glucose is a very important energy source for the central nervous system and to maintain energy levels in the muscle during rigorous activity. Glucose can be used as an energy source the cells in the body. Like the liver, the muscle can also store glucose as glycogen. Because blood glucose levels have to be maintained in a certain range, the liver tightly controls how much glucose is released into the bloodstream.

In the big picture, regardless of what carbohydrate goes into our mouth, the only carbohydrate that is made widely available to our body tissues is glucose. The liver is the primary control center that makes this happen. Interestingly, if the liver were to fail in its job, significant damage to the body would occur. Galactose and fructose cannot be metabolized well in other body tissues and can be harmful to them.

Leftover Carbohydrates: The Large Intestine

Almost all of the carbohydrates, except for dietary fiber, are efficiently digested and absorbed into the body in the small intestine. The undigested dietary fiber moves on to the large intestine. Within the large intestine, the bacteria break down some of the dietary fiber and use it for energy. In this role, the fiber is acting as a prebiotic as discussed in the digestion chapter. The products of bacterial digestion of fiber are short-chain fatty acids and some gasses (It sounds odd, but the bacteria metabolize the fiber and produce very small fats). The short-chain fatty acids can be used by the bacteria to make energy. They also can be absorbed by the cells of the large intestine. They can either be metabolized by the cells in the large intestine or released into the blood stream for use by other body cells. The yield of energy from dietary fiber is about 2 Calories per gram for humans but this is highly dependent upon the fiber type. These short-chain fatty acids are typically considered a benefit to the body.

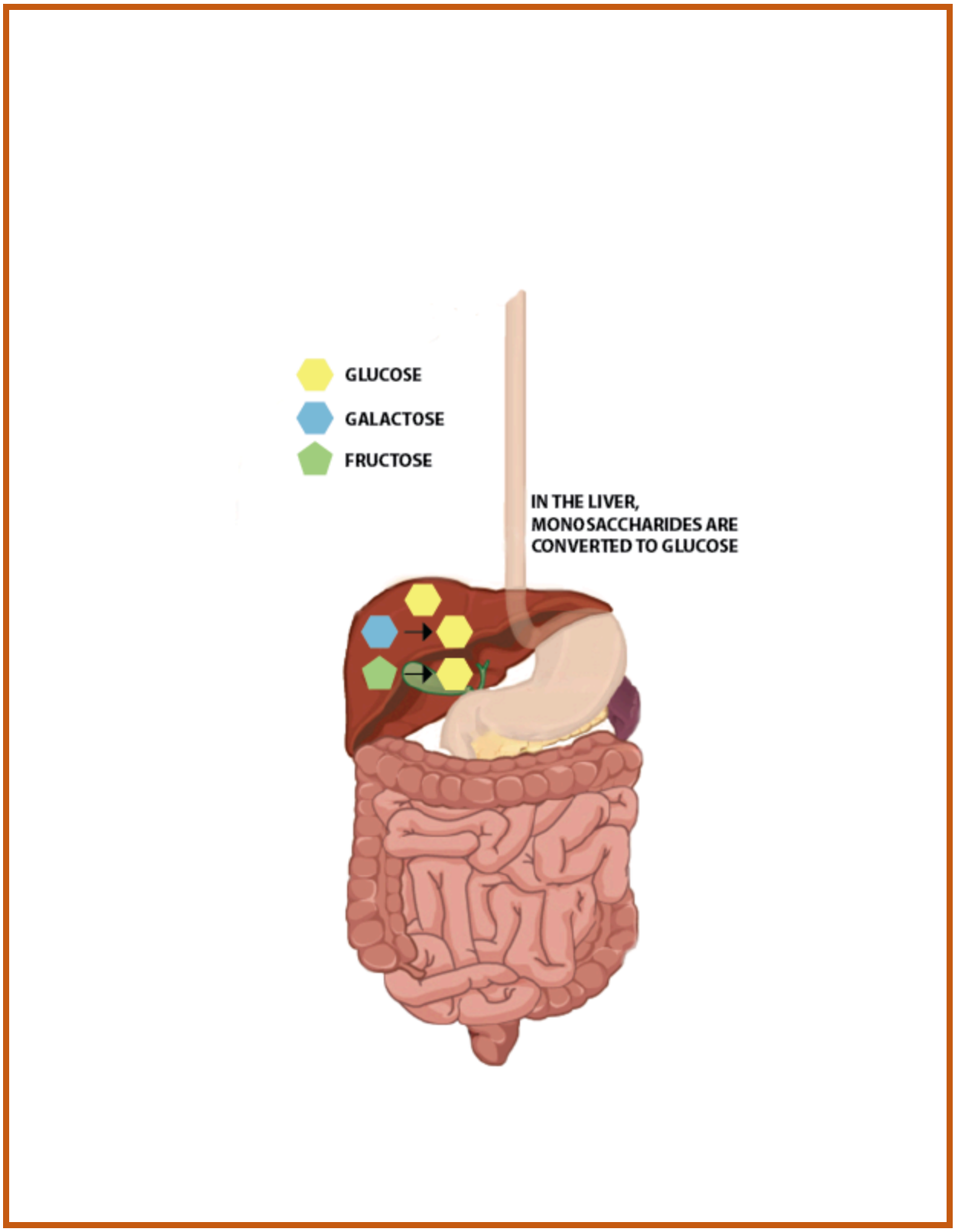


Figure 5.12: The conversion of fructose and galactose to glucose in the liver. Image by OpenStax College under CC BY 3.0 license with edits.

Key Takeaways

- *Carbohydrate digestion begins in the mouth with salivary amylase and is completed in the small intestine, where various enzymes break down starches and disaccharides into monosaccharides.*
- *Only monosaccharides (glucose, fructose, and galactose) are small enough to be absorbed into the bloodstream.*
- *All absorbed monosaccharides are transported to the liver, which converts galactose and fructose into glucose, making glucose the primary source of carbohydrate energy for the body's cells.*
- *Lactose intolerance is a condition caused by deficiency of the enzyme lactase, leading to uncomfortable digestive symptoms when lactose is consumed.*
- *Undigested dietary fiber reaches the large intestine, where it is broken down by bacteria to produce short-chain fatty acids, which can provide a small amount of energy.*

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8.3

Carbohydrate Regulation in the Body

5.3 Carbohydrate Regulation in the Body

Glucose is an important energy source for almost all cells in the body and of primary importance for the central nervous system. Glucose levels in the blood are tightly controlled; having either too much or too little glucose in the blood can have health consequences. Glucose levels are regulated in the blood through a feedback mechanism. An oven is a good example of how this process works. When you set the temperature to cook homemade bread at 375°F, the thermostat senses the temperature and sends an electrical signal to turn the elements on and heat up the oven. When the temperature reaches 375°F, the thermostat senses the temperature and sends a signal to turn the element off.



Setting the temperature control on oven as a comparison to glucose regulation. Image by SHVETS Production on Unsplash.

Similarly, your body senses blood glucose levels and maintains the glucose "temperature" in the target range. The glucose thermostat is located within the cells of the pancreas. After eating a meal containing carbohydrates, glucose levels rise in the blood. Insulin-secreting cells in the pancreas (beta cells) sense the increase in blood glucose and release the hormone **insulin**, into the blood. Insulin sends a signal to the body's cells to remove glucose from the blood by transporting it from the blood to the insides of the cells (see Figure 4.13A/B). The presence of insulin in the blood signals the body that it

has just been fed and that there is fuel (glucose) for the cells to use. Insulin has an opposing hormone called glucagon. As the time after a meal increases, glucose levels decrease in the blood. Glucagon-secreting cells in the pancreas sense the drop in glucose and, in response, release **glucagon** into the blood. Glucagon signals the liver to break down glycogen and release the stored glucose into the blood (see Figure 4.13A/B). In addition, glucagon can initiate the production of glucose from other substances, such as protein and glycerol in the liver. This pathway is called **gluconeogenesis**. Under normal circumstances, glucagon is able to release glucose from glycogen and increase glucose production in the liver to maintain blood sugar in the normal target range of 70-120 mg/dl (about 1 teaspoon). This allows for a continuous supply of glucose to tissues. A constant supply of glucose is particularly important for the brain and central nervous system which both rely on glucose as an energy source.

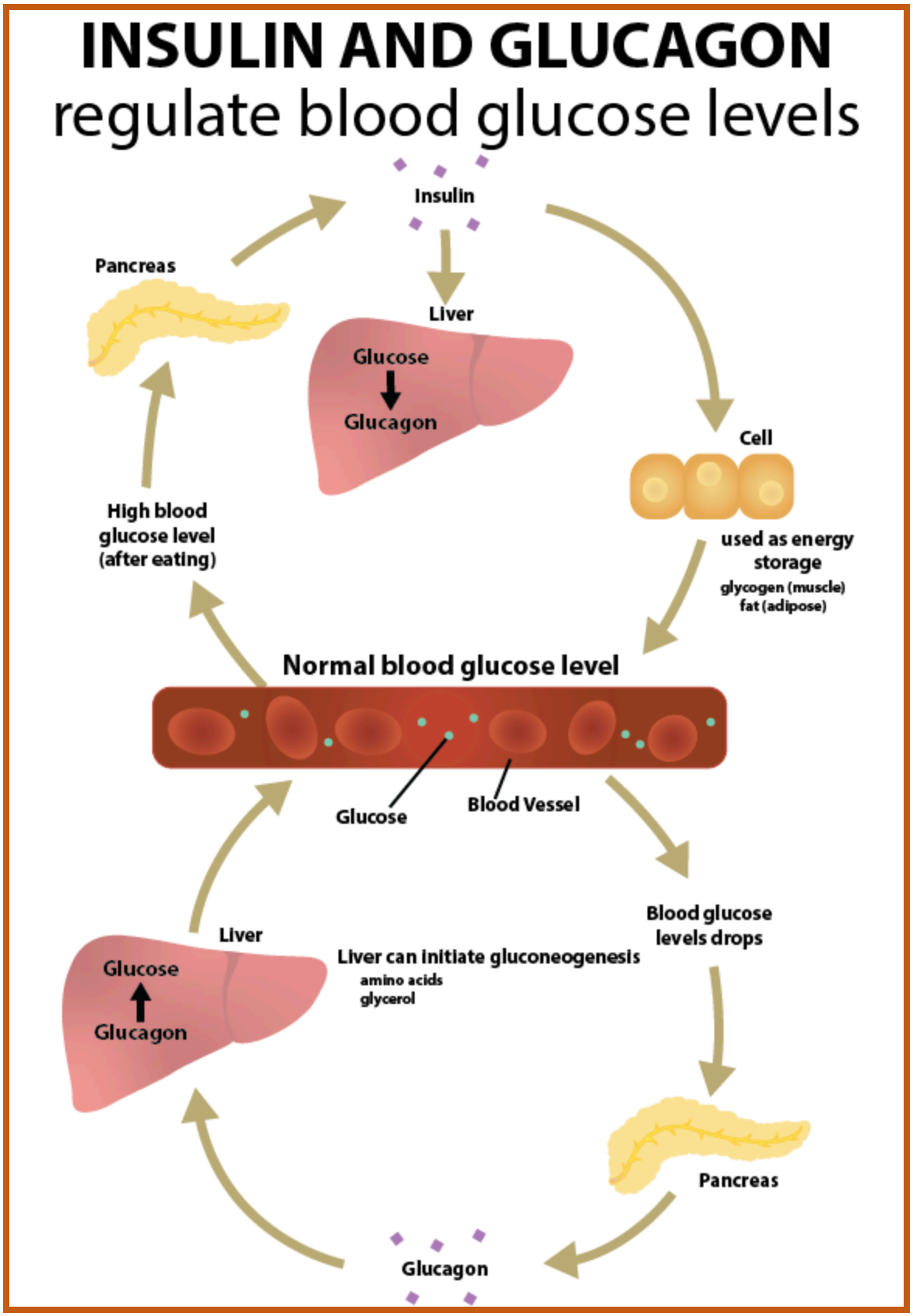


Figure 5.13A: Insulin and Glucagon regulate sugars in the blood. Images by Cancer Research UK / Wikimedia Commons under CC BY-SA 4.0 license with edits.

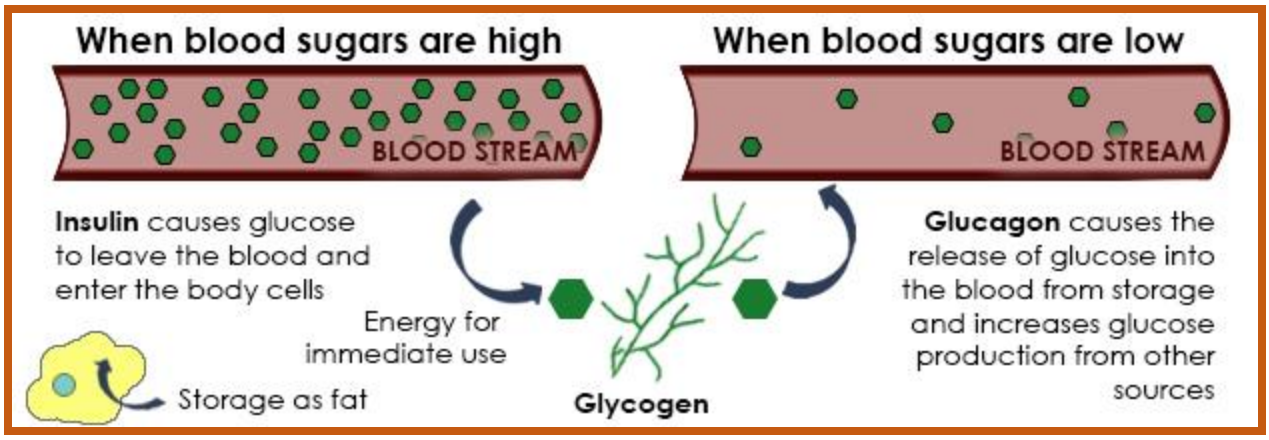


Figure 5.13B: The role of insulin and glucagon in the regulation of blood sugars.

Taking a close look at diabetes is a good way to gain a better understanding and appreciation for carbohydrate regulation in the body. Diabetes is categorized into two basic forms, Type 1 and Type 2. **Type 1 diabetes** develops when the pancreas stops producing insulin. As a result, the blood glucose derived from the carbohydrates that are eaten gets stuck in the blood stream and can't get into the liver and adipose cells. A normal blood glucose level ranges between 70–120 mg/dl. A person with untreated type 1 diabetes may have blood sugars 800- 1000 mg/dl. If not treated this will eventually be deadly. In **type 2 diabetes** the pancreas is still producing plenty of insulin, and initially even excessive amounts of insulin are produced, but the body cells will not respond to it. This is referred to as being insulin resistant. Even though these two types of diabetes appear similar in many ways, the treatment approach is very different. Type 1 diabetes requires insulin treatments. Since insulin levels are above normal in type 2 diabetes giving additional insulin is not often a good approach. Lifestyle change, including dietary changes, and medications are used to treat type 2 diabetes.

Glycemic Index

Not all carbohydrates affect the blood glucose with the same intensity and speed. Some foods raise blood sugars rapidly and with a higher intensity, other foods have a lower and more gradual response. The magnitude in which a food raises blood glucose is called the **glycemic index**. Refined foods and foods high in amylopectin and simple sugars like glucose tend to have a high glycemic index value. Whole foods high in fiber, fat and fructose tend to have a lower glycemic index. For instance, a potato is very high in amylopectin and amylose and has a very high glycemic index. However, if you eat the potato with the skin, the glycemic index of the potato drops because of the fiber that is found in the potato skin. The fiber slows the absorption of the glucose in the intestine. Alternatively, if you put butter on the potato, the glycemic index drops because of the fat content. The presence of fat in the digestive tract slows digestion. High glycemic foods raise blood sugars quickly and intensely; in conjunction, they also tend to raise insulin levels higher and faster. The presence of insulin in the blood globally sends a message to store not only glucose, but fat as well, and in some people is associated with weight gain and the potential problems that can be associated with excess weight. There is some evidence that indicates those who choose low glycemic foods more often may have a lower risk of developing diseases such as Type 2 diabetes and cardiovascular disease.[7]

Nonetheless, caution should be exercised using the glycemic index to judge the healthiness of foods and in the determination of what foods to eat. For example, because French fries are deep fried they have a lower glycemic index than a baked potato. Based on the glycemic index alone a person could "incorrectly" conclude that eating the French fry is better than eating the potato. The potato is much more nutrient dense than the fry. Also, foods are rarely eaten alone. Combining low and high

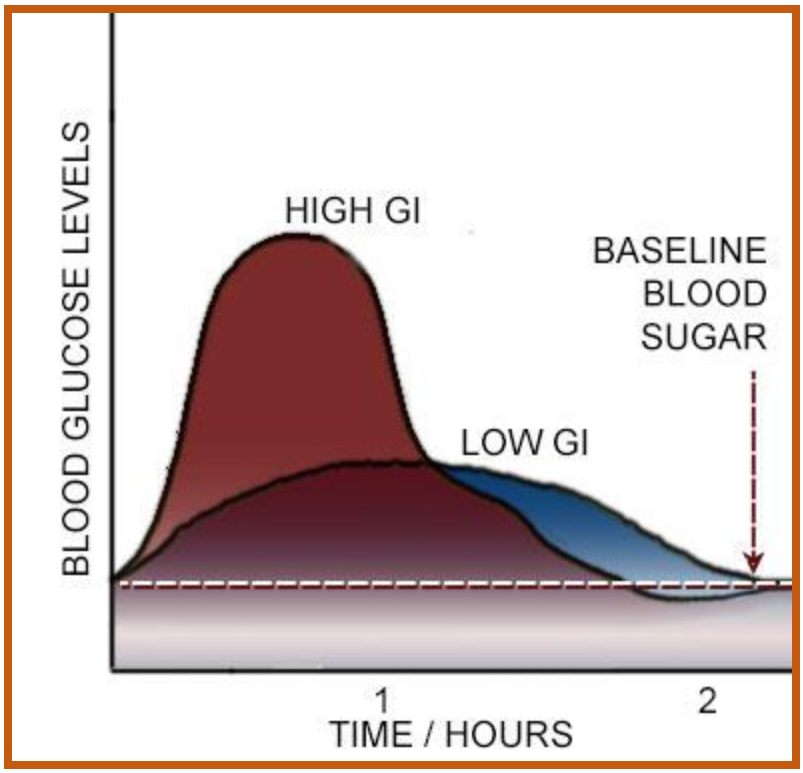


Figure 5.14: The glycemic index measures the effects of foods on blood-glucose levels. Provided by Debra Lowe.

glycemic index foods in a meal can balance out the overall glycemic effect. A person's glycemic response to foods will also change depending on a variety of factors, such as fitness level, the time of day food is eaten, and the temperature of the food. In addition, meats and fats do not have a GI since they contain very little carbohydrates. However, that should not make them available for over-consumption. The best way to naturally achieve practical glycemic moderation is to choose nutrient-dense, whole foods as much as possible and practice the principles of variety, moderation, and balance as described in Choose MyPlate and the Word of Wisdom. This would include regular consumption of whole grains, fruits, vegetables, nuts, seeds, and legumes.

Key Takeaways

- *The body tightly controls blood glucose levels using a feedback loop involving two pancreatic hormones: insulin and glucagon.*
- *When blood glucose is high, insulin signals cells to absorb glucose; when it is low, glucagon signals the liver to release stored glucose.*
- *There are two main types of diabetes: Type 1, where the body stops producing insulin, and Type 2, where the body's cells become resistant to insulin.*
- *The glycemic index measures how much a food raises blood glucose, with factors like fiber and fat content lowering a food's score*
- *It is recommended to focus on a diet of nutrient-dense, whole foods rather than relying solely on a food's glycemic index, which can be misleading.*

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8.4

Functions of Carbohydrates

5.4 Functions of Carbohydrates

There are five primary functions of carbohydrates in the human body. They are, energy production, energy storage, building macromolecules, sparing protein, and assisting in lipid metabolism.

Energy Production

The chief role of carbohydrates is to supply energy to all body cells. Most cells can use glucose and fat as effective energy sources. But some cells are highly dependent on glucose alone. For example, red blood cells and brain cells depend greatly on glucose. Muscle cells use both carbohydrate and fat effectively, but when activity is very intense glucose use become a priority. About 70 percent of the glucose entering the body from digestion is redistributed (by the liver) back into the blood for use by other tissues. Cells that require energy allow the movement of glucose from the blood into the cell through a transport protein in their membranes. The energy from glucose comes from the chemical bonds between the carbon atoms. Sunlight energy was required to produce these high-energy bonds in the process of plant photosynthesis. Cells in our bodies break these high energy bonds found in glucose releasing energy for our use. This process is called cellular respiration.

A cell uses many chemical reactions in multiple enzymatic steps to allow for a slow and efficient release of energy held within the chemical bonds in glucose. This is necessary because the cells cannot use carbohydrate, protein or fat directly for energy; they must have Adenosine Triphosphate (ATP). The following analogy can be used to demonstrate this principle. An employer has 10 workers. Each is paid $10 per day. At the end of the day, the employer goes to the bank to get $100 to pay his workers. If the bank gives the employer a $100 bill, will the boss be able to pay his workers? No. Even though the $100 bill is the correct amount of money to pay the workers, the worth of the money cannot be shared with the workers when it is in the form of just one bill. Converting the $100 bill into smaller units of $10 bills, enables the boss to distribute the value of $100 among the workers. Likewise, food contains lots of valuable energy, but it is useless to the various cells of the body until it can be converted into smaller, usable units called ATP (see Figure 4.15)

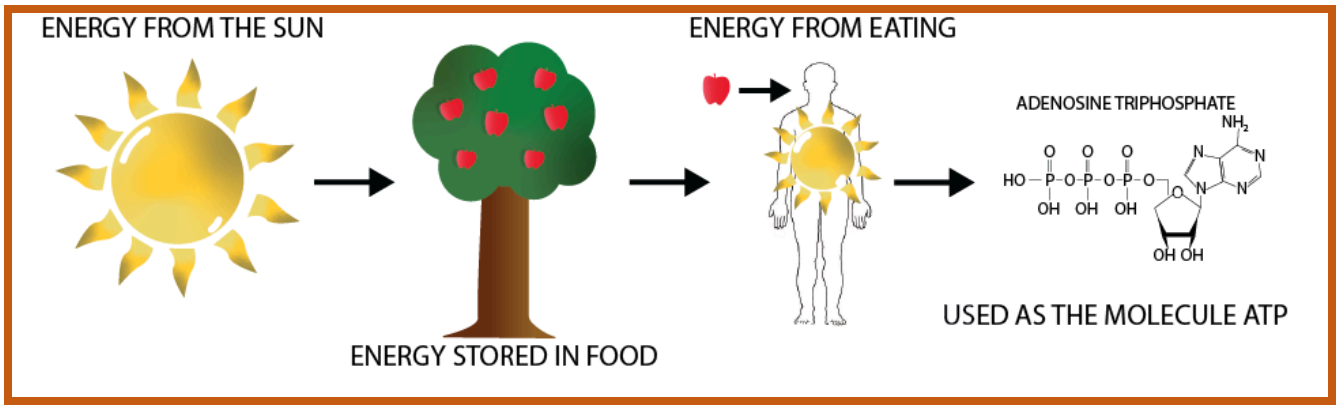


Figure 5.15: The conversion of complex energy forms to simple usable forms. Person Outline Photo by ఇందూ జ్ఞాన వేదిక under CC BY-SA 3.0 license with edits.

The first stage in the breakdown of glucose is called glycolysis. Glycolysis, or the splitting of glucose, occurs in an intricate series of ten enzymatic-reaction steps in the cytoplasm of cells. At the end of glycolysis, glucose (6 carbons) has been split into two molecules of pyruvate (3 carbons each). A little bit of energy (in the form of ATP) is extracted from the conversion of glucose to pyruvate, but the vast majority of the energy is still locked up in the pyruvate or other byproducts. The rest of the energy will be extracted from the pyruvate inside the mitochondria. This is why the mitochondria are called the power center of cells (see Figure 4.16).

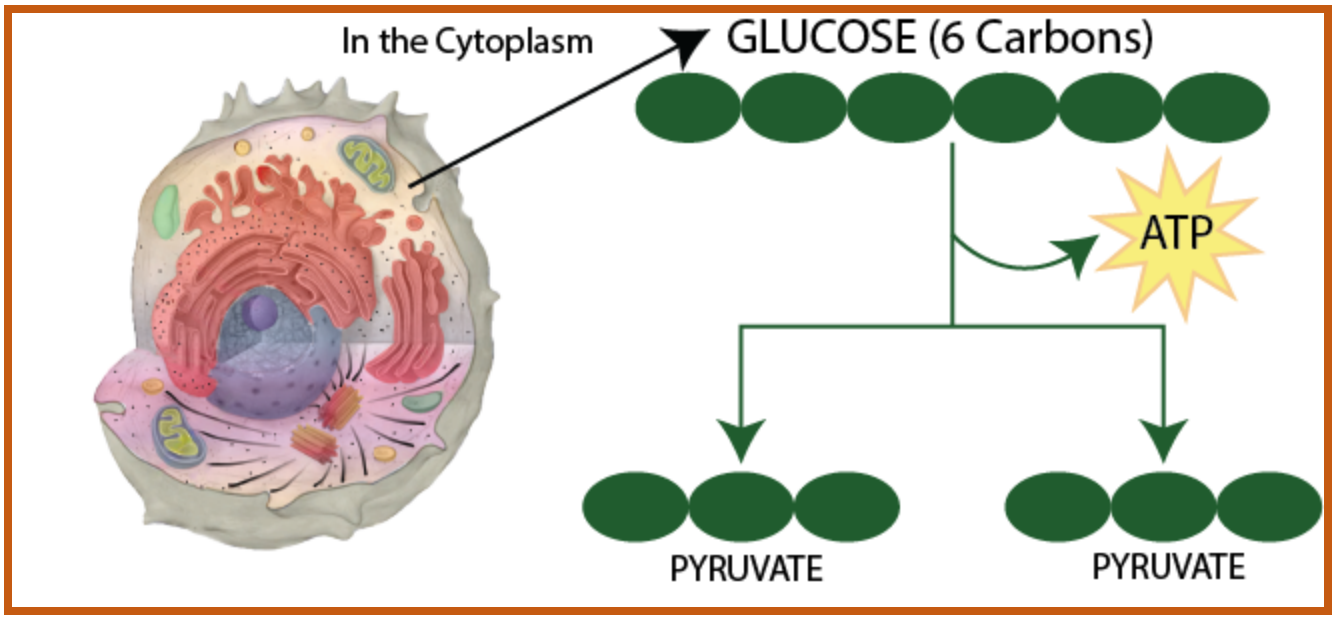


Figure 5.16: In the cytoplasm of the cell, glucose is converted to 2 molecules of pyruvate. If oxygen supply is low, the pyruvate is converted to lactate. Cell Image by Koswac under CC BY-SA 4.0 license with edits.

For the next phase of energy extraction to happen, sufficient oxygen must be available in the mitochondria. If oxygen is in short supply, the pyruvate will be stuck in the cytoplasm of the cell and be converted to lactate. The most common example of this occurs in high intense activity (like a 100-meter sprint). In this situation, our need for energy has exceeded our body's ability to take in oxygen and deliver it to the muscle and lactate levels increase in the body. This is called anaerobic glycolysis and can only continue for a short period. When a critical level of lactate is reached, metabolism slows down to allow the oxygen supply to catch up.

The second stage of glucose breakdown occurs in the mitochondria. The pyruvate molecules move out of the cytoplasm into the mitochondria. There they are converted to a compound called acetyl-CoA. Acetyl-CoA enters another pathway called the Krebs cycle (or the citric acid cycle or TCA cycle –they are all the same thing). There, the remaining energy is extracted from what was once glucose and is prepared for conversion to ATP. The electron transport chain is the final piece of the process. Most of the ATP production occurs within the electron transport chain (see Figure 4.16).

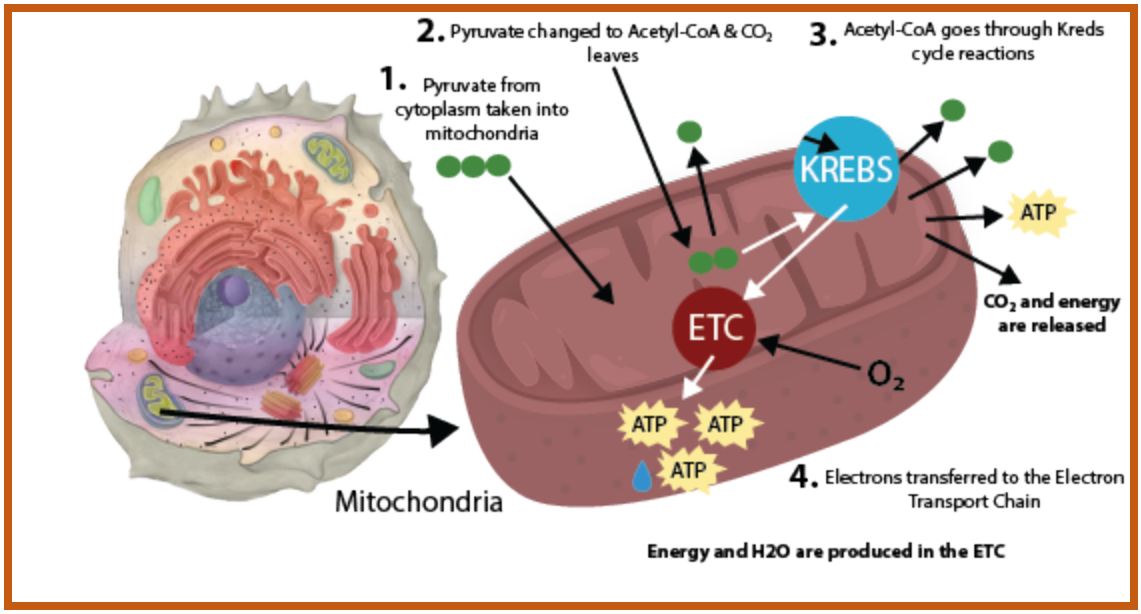


Figure 5.17: Within the mitochondria pyruvate is converted to acetyl-CoA and the energy extraction is completed. Cell Image by Koswac under CC BY-SA 4.0 license with edits.

Energy Storage

If the body already has enough energy to support its functions, the excess glucose can be stored as glycogen (the majority of which is stored in the muscle and liver). A molecule of glycogen may contain more than fifty thousand single glucose units and is highly branched, allowing for the rapid release of glucose when it is needed to make cellular energy. (Figure 4.18 shows the branch structure of glycogen.) In between meals or during exercise are times when the body relies on glycogen stores to provide glucose for energy. During rigorous exercise, glycogen stores can be used up within 1-2 hours. This is the point during physical exertion that athletes refer to as hitting the wall or bonking. The body still has plenty of fat to provide energy, but ATP cannot be made nearly as fast from fat as it can be from carbohydrate. During exercise, this can be a problem if an athlete is trying to keep up a high level of exercise intensity.

Building Macromolecules

Although most absorbed glucose is used to make energy, some glucose is converted to ribose and deoxyribose, which are essential building blocks of important macromolecules, such as RNA, DNA, and ATP. If all of the energy, glycogen-storing capacity and building needs of the body are met, excess glucose can be used to make fat. This is why a diet too high in carbohydrates and calories can add on the fat pounds—a topic that will be discussed later.

Sparing Protein

In a situation where there is not enough glucose to meet the body's needs, glucose is made from some amino acids through a process called **gluconeogenesis**. Because there is no way for the body to store large pools of free amino acids, this process requires the catabolism (break down) of muscle tissues to provide amino acids for glucose production. Consuming enough

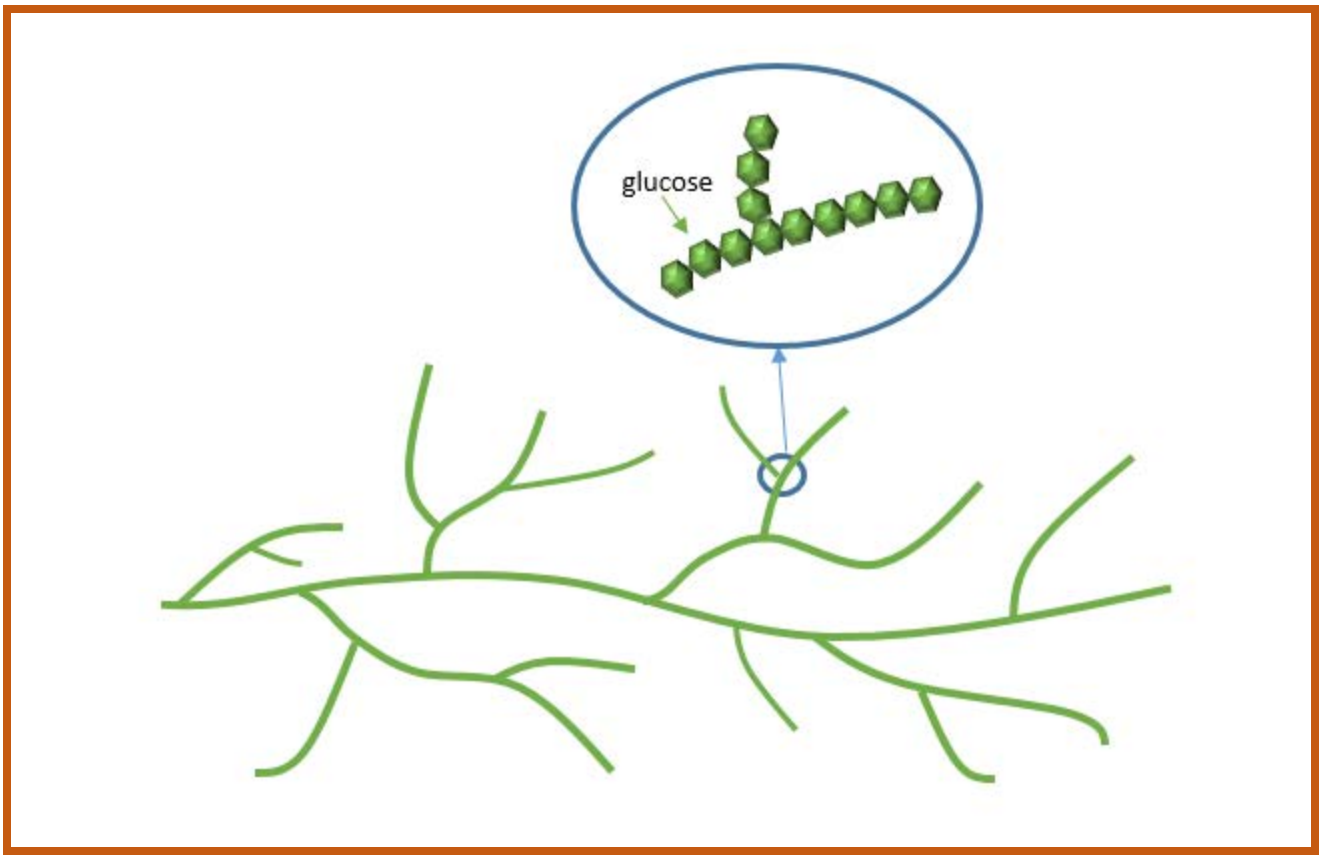


Figure 5.18: Glycogen

carbohydrate to provide for the body's glucose needs allows the body to spare the body's protein for its primary functions, like building muscle. Under normal circumstances, gluconeogenesis can produce glucose at a sufficient speed to maintain normal blood glucose levels, such as during an overnight fast. In situations where glucose is in high demand, such as during prolonged rigorous exercise, gluconeogenesis will not produce glucose quickly enough to meet the body's needs. During rigorous exercise, eating food sources of glucose becomes essential to sustain performance as well as spare protein.

Ketosis

Ketosis is a metabolic condition resulting from an elevation of ketone bodies in the blood. Ketone bodies are an alternative energy source that cells, including brain cells, can use when glucose supply is insufficient, such as during fasting or when eating a low carbohydrate diet. Ketone bodies are made from lipid. Ketone bodies are acidic and high elevations in the blood can cause the body to become too acidic. Highly elevated ketone levels is rare in healthy adults but can occur with alcohol abuse, severe calorie restriction and in individuals who have Type 1 diabetes.

The minimum amount of carbohydrate in the diet required to inhibit ketosis in healthy adults is approximately 50 grams per day.

Carbohydrates are critical to support life's most basic function—the production of energy. Without energy, none of the other life processes are performed. Although our bodies can synthesize glucose, it comes at the cost of protein break down. As with all nutrients, carbohydrates are to be consumed in moderation as having too much or too little in the diet may lead to health problems.

Key Takeaways

- *The primary function of carbohydrates is to provide energy to all body cells, especially the brain and red blood cells, which are highly dependent on glucose.*
- *The body stores excess glucose as glycogen int he liver and muscles, creating an energy reserve that can be quickly accessed when needed, such as during exercise.*
- *The body uses carbohydrates to "spare" protein, preventing the breakdown of muscle tissue for energy through a process call gluconeogenesis.*
- *Carbohydrates are essential for building important macromolecules like RNA, DNA, and ATP.*
- *When glucose supply is insufficient, the body can enter a metabolic state called ketosis, where it uses an alternative energy source called ketone bodies, which are made from lipids.*

References (see below)

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8.5

Role of Grains in Health and Disease

5.5 Role of Grains in Health and Disease



Brother keller had an image? *Various types of grains including oats, rice, wheat, barley, and buckwheat. Image by alleksana via pixabay.*

The inclusion of nutrient dense carbohydrates in meal planning is consistent with current science and revelation. After extensive research and review of the literature, the group of experts that wrote Dietary Guidelines for Americans 2020 maintained that appropriate selection of carbohydrate rich foods is consistent with optimal health. The Word of Wisdom is also clear in its support of grains of all types, as well as fruits and vegetables for health promotion. Obesity and many other health problems appear to be unfairly blamed on carbohydrates as a whole. BUT… when choosing carbohydrate rich foods there are some important considerations:

1. When choosing grains, choose a variety of nutrient-dense whole grains. Much of what is made available to the consumer is refined grains that contain added fats and sugars.
2. Be aware of added sugars contribution to the total carbohydrate content in any product you may choose (remember sugars are also in the carbohydrate family). Added sugars add calories but little vitamins and minerals.

Excessive consumption of refined carbohydrates with added fats and sugars, especially when connected with the over-consumption of calories, is detrimental to health.

Refinement

The refining process of grains removes many important nutrients. By law, thiamin, riboflavin, niacin, iron and folate must be added back (enriched). However, other important nutrients remain lost from the grain, such as fiber, magnesium, zinc, copper and many phytochemicals as well (Refer to Figure 5.8 in section 5.1).

There is a wealth of scientific evidence that supporting that replacing refined grains in the diet with whole grains that decrease the risk of developing a number of common serious health issues.[8] Americans typically do not consume 50% or more of their grain food choices as whole grains. Across all age groups nearly 100% of American's do not meet this goal (see Figure 5.19).[9]

A large meta-analysis published in the British Medical Journal in 2016 reported that the consumption of whole grains was associated with a reduction in coronary heart disease, cardiovascular disease, respiratory disease, infectious disease, diabetes and mortality from all causes.[1] Both the American Heart Association and the American Cancer Society support the consumption of whole grains for disease prevention.[10,11]

The Word of Wisdom specifically mentions the use of wheat, but several times emphasizes that all grains are ordained for the use of men. Many areas of the world are not able to grow wheat well. Over time, as exposure to different grain products produced around the world has increased in the United States, a wide variety of healthy options have been made available. Grains differ in their nutritional content, availablity and cultural acceptance, When possible, choose a variety of whole grains to meet your nutritional needs. Refer to Table 2 for a comparison of the nutritional content of several whole grains.

Nutrients	Whole wheat flour (100g)	Quinoa, uncooked (100g)	Millet, raw (100g)	Rye grain (100g)	Flaxseed (100g)
Calories (kcal)	340	368	378	338	534
Protein (g)	13.21	14.12	11.02	10.34	18.29
Fiber (g)	10.7	7	6.7	15.1	27.3
Calcium (mg)	34	47	8	24	255
Potassium (mg)	363	563	195	510	813
Copper (mg)	363	563	195	510	813
Selenium (µg)	61.8	8.5	2.7	13.9	25.4

Nutrients	Whole wheat flour (100g)	Quinoa, uncooked (100g)	Millet, raw (100g)	Rye grain (100g)	Flaxseed (100g)
Niacin B-3 (mg)	4.957	1.52	4.72	4.27	3.08
Folate (µg)	44	184	85	38	87
Betaine(mg)	72.8	630.4	n/a	146.1	3.1
Polyunsaturated fats (g)	1.167	3.292	2.134	0.767	28.73

Table 2: Nutrient comparison of several whole grain products (100 grams is roughly ¾ cups)

Whole Grains and Colon Health

One of the ways that whole grains promote good health is through their contribution to daily fiber intake. The benefits of fiber were outlined earlier in this chapter. Many whole grains are particularly rich in insoluble fiber. Insoluble fiber is particularly good at preventing constipation and the development of diverticulosis and diverticulitis. **Diverticulosis** is a harmless condition characterized by out-pocketings of the colon. **Diverticulitis** occurs when the out-pocketings in the lining of the colon become inflamed and can be painful (see Figure 5.20)



Figure 5.20: Diverticulosis and diverticulitis. CImage by Blausen.com staff (2014) "Medical gallery of Blausen Medical 2014". WikiJournal of Medicine 1 (2). DOI:10.15347/wjm/2014.010. ISSN 2002-4436. under CC BY-SA 4.0 license with edits.

More than 50% of the population of the United States will have diverticulosis by the age of 50. Often, no symptoms are associated with this condition, most people will be unaware they have it. Symptoms may include cramping, bloating and constipation or more serious symptoms such as bleeding. Ten to 25% of people that have diverticulosis will go on to develop diverticulitis. (4) Diverticulitis can be very painful and potentially dangerous. Evidence supports the use of fiber in the prevention and treatment of this disease.[12] The beneficial effects of fiber may not only be from the direct presence of fiber in the colon (softens stools, keeps things moving), but also because some fiber (prebiotics) support the good bacteria living in our colon.

Identifying whole grains

The identification of whole grain products can be a challenge when you are in the grocery store. "Whole grains" on the label does not always mean the product is made with 100% whole grains. It is important to realize that brown colored breads are not always healthier than white bread because the brown color may come from molasses or caramel. The Food and Drug Administration (FDA) has provided the food industry with specifics on how to label whole-grain foods. The best method to ensure the product is made from 100 percent whole grains is to check the ingredient list. One-hundred percent whole-grain products list **whole** grains as the first ingredient (for example whole wheat bread, would list whole wheat flour as the first ingredient). One-hundred percent whole grain products do not contain other refined flours such as wheat flour (which is just white flour), yellow corn flour or other refined grain products. The Dietary Guidelines for Americans gives this regarding the selection of whole grains:

> *"At least half of total grains should be whole grains. Individuals who consume all of their grains as whole grains should include some that have been fortified with folic acid. Grain-based foods in nutrient-dense forms limit the additions of added sugars, saturated fat and sodium."*[2]



Whole Wheat Bread. Photo by Sergio Arze on Unsplash.

Key Takeaways

- *Scientific evidence and dietary guidelines support the consumption of nutrient-dense carbohydrates like whole grains, while cautioning against refined grains with added sugars.*
- *The refining process removes key nutrients and fiber from grains, and the enrichment process only adds back a limited number of these lost nutrients.*
- *A large body of evidence shows that consuming whole grains is associated with a reduced risk of chronic diseases, including heart disease, diabetes, and certain cancers.*
- *Whole grains, particularly their insoluble fiber, are essential for colon health and help prevent conditions like constipation and diverticulitis.*
- *To ensure a product is a whole grain, you should check the ingredient list for the word "whole" as the first ingredient, a brown color is not a reliable indicator.*

References (see below)

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- 2. Doctrine and Covenants. Salt Lake City, UT: Intellectual Reserve, Inc; 1981:176.
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8.6

Added Sugars

5.6 Added Sugars



Figure 5.21: Identification of added sugars in food products (The added sugars are outlined in red in the ingredient list)

Added sugars are sugars that have been added to food products during preparation or processing. Added sugars do not include sugars that occur naturally in whole foods (such as those found in fruits like berries, bananas, apples). Agave, brown sugar, corn syrup, dextrose, fructose, high fructose corn syrup, honey, maple syrup, raw sugar and sucrose (table sugar made from sugar cane or sugar beets) are all considered "added sugars" when added to foods. All added sugars contribute calories, but no additional nutrients. In fact, the overconsumption of sugar has been implicated in the development of type 2 diabetes and other chronic metabolic diseases. The amount of added sugar in a processed food is listed on the Nutrition Facts label. The names of the added sugars must be included in the ingredient list. It is required that added sugars are listed as individual items in the ingredient list. (See example on Figure 5.21.)

Ingredients: Whole grain rolled oats, **brown sugar**, vegetable oil, **honey**, raisins, wheat, salt

It is helpful to understand that 4 grams of added sugar on a food label represents about a teaspoon of added sugar. For instance, many commercial yogurt products have as much as 12 grams of added sugar. This represents three teaspoons of added sugar in a 6 or 8-ounce yogurt. All the sugar in a soft drink is added sugar. One 20-ounce soft drink may contain up to 65 grams of added sugar or roughly 16 teaspoons (Figure 5.22).

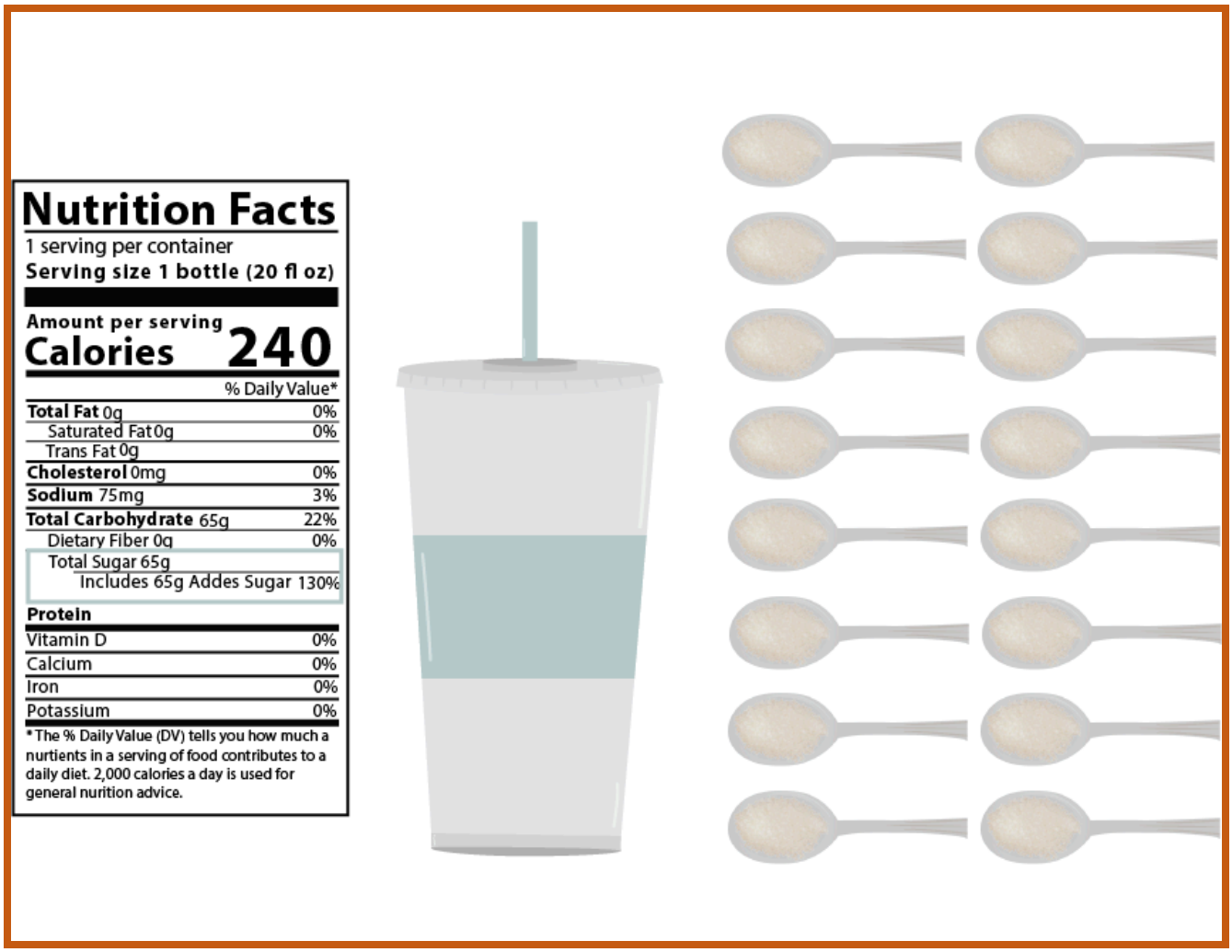


Figure 5.22: This 20-ounce can of soda contains 65 grams of added sugar (This translates to about 16 teaspoons of "Added Sugar") Created by AP.

According to the report given in the 2020-2025 Dietary Guidelines for Americans, the majority of the added sugar consumed in the American diet comes in the form of beverages such as "soft drinks, fruit drinks, sweetened coffee and tea, energy drinks, alcoholic beverages, and flavored waters" (see Figure 5.22).[15] Snacks and sweets such as "cakes, pies, cookies, brownies, doughnuts, sweet rolls, and pastries; dairy desserts such as ice cream, other frozen desserts, and puddings; candies; sugars; jams; syrups; and sweet toppings" are also significant contributors.15 It is also important to note that another 18% of the added sugars in our diet come from foods made from grains and flours, dairy and combination foods such as frozen meals. These are items we often don't even suspect of containing added sugars. "Added sugars account on average for almost 270 Calories, or more than 13 percent of calories per day in the U.S. population and are particularly high in children, adolescents and young adults." 2 According to the math, that amount of added sugars (if eaten in excess of caloric needs) could account for 28 pounds of weight gain in 1 year.

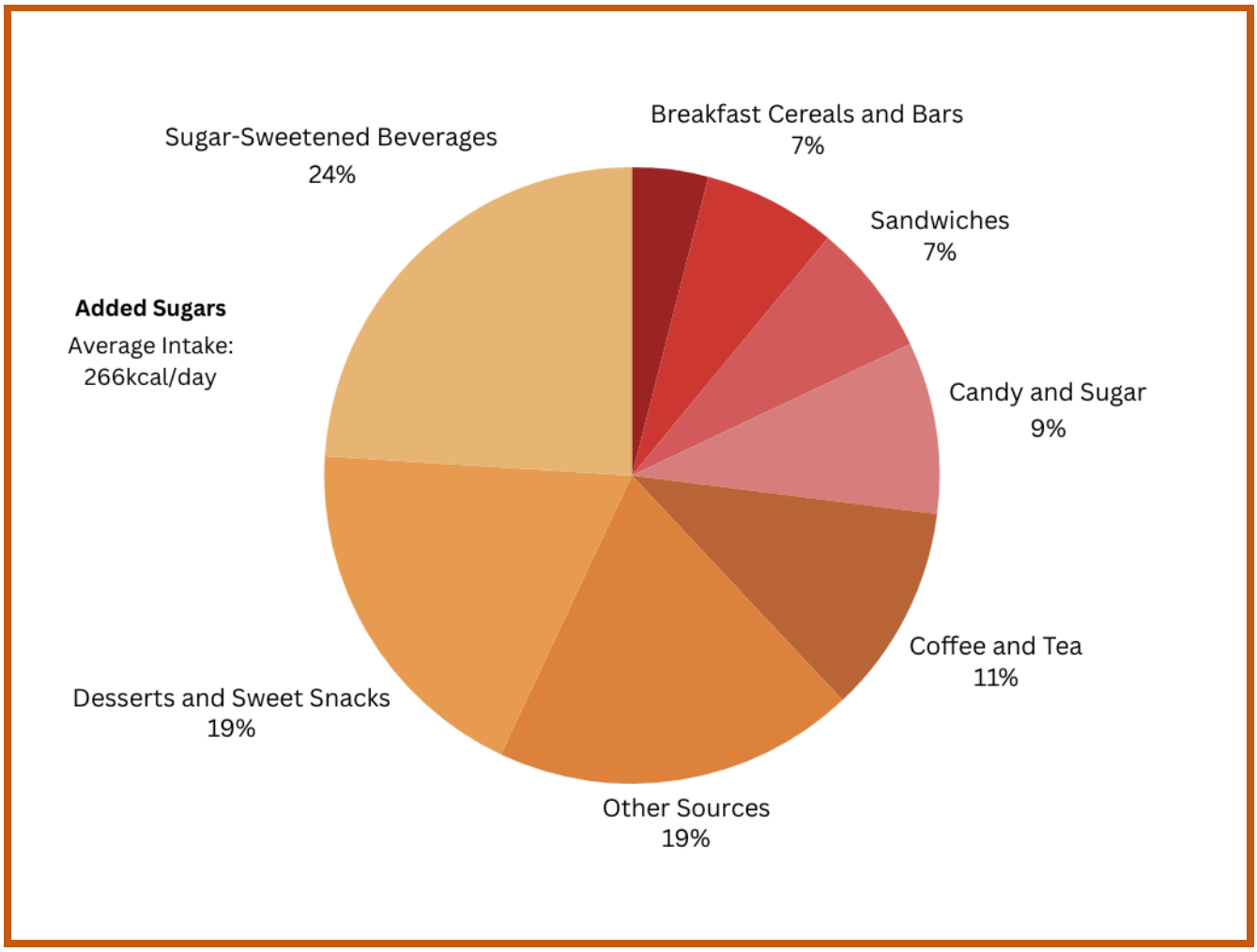


Figure 5.23: Sources of added sugars in the American diet2. Created by AP.

Health Implications of Added Sugar

To understand the magnitude of the health problem in the United States, consider this: approximately 130 million adults are overweight (BMI of 25 to 29.9) and 30% of these people are obese (BMI of 30 or more). Overweight and obesity also affects young adults, youth, children and babies. Serious health consequences often follow them into adulthood. Negative health consequences strongly linked to being overweight or obese include: type 2 diabetes, cardiovascular disease, arthritis, depression and some cancers.

An obsession with sugary foods and beverages, and refined grains contribute to the epidemic proportion of people who experience overweight and obesity. Other contributing factors are: the consumption of processed foods instead of whole foods, and a sedentary lifestyle. The magnitude of the role of added sugars in our global health crisis is slowly becoming more clear. Research links sugar consumption to increased risk for developing several chronic metabolic diseases such as: heart disease, liver disease, weight gain, obesity and type 2 diabetes. Sugar sweetened beverages (soda, sport drinks, and fruit drinks) are big offenders.

Whether different sugars have differing negative metabolic effects is a hot topic both in research and the popular media. For example: High fructose corn syrup (HFCS) has been targeted as being unhealthier than regular sugar. HFCS is an inexpensive liquid sweetener made from corn. It is composed of a sucrose solution of glucose and fructose. (Sucrose is 50% glucose and 50% fructose.) In HFCS, the percentage of fructose is higher than glucose which makes HFCS sweeter than sucrose because

fructose tastes significantly sweeter than glucose. HFCS contains more fructose than sucrose. Because of its low cost, sweeter taste, and ease of mixing into a wide variety of processed foods, food manufacturers often use HFCS instead of sugar. Despite all the hype about high fructose corn syrup, there is not clear evidence to support that it is more detrimental to health than other common sweeteners that are added to foods.

Sugar Intake Guidelines

All sugars are rich in calories and exceedingly poor in nutrients. The Dietary Guidelines for Americans 2020-2025 and the World Health Organization recommends no more than 10% of our caloric intake should come from added sugars. This is an "upper limit" and not a goal amount to be consumed each day.) For example: For a woman eating 2000 Calories per day, this is equal to no more than 12.5 teaspoons of added sugar per day. Data from 2001-2004 show that Americans eat an average of 22.5 teaspoons of added sugars each day. The American Heart Association's recommendation for maximum sugar consumption is even more aggressive: For women the recommendation is no more than 6 teaspoons (25 grams) of added sugars per day, and for men the recommendation is no more than 9 teaspoons (36 grams) of added sugars per day. This guideline was established in 2010 after a review of the literature regarding the effects of sugar consumption on heart health. In its Dietary Reference Intakes (DRIs), the Institute of Medicine recommends limiting added sugar consumption to no more than 25% of total energy. (This is not a recommended intake.)

Key Takeaways

- *Added sugars are sugars and syrups added to food during processing and provide "empty calories" without additional nutrients.*
- *The main source of added sugars in the American diet are sweetened beverages, sweets, and snacks, but they are also present in many processed foods that may not be suspected of containing them.*
- *The overconsumption of added sugars is linked to a higher risk of developing obesity and chronic metabolic diseases such as type 2 diabetes and heart disease.*
- *There is no clear evidence to support the claim that high fructose corn syrup is more harmful than other common sweeteners.*
- *Major health organizations, such as the American Heart Association, recommend significantly limiting added sugar intake to no more than 6-9 teaspoons per day.*

Reference (see below)

- 2. U.S. Department of Agriculture and U.S. Department of Health and Human Services. Dietary Guidelines for Americans, 2020-2025. 9th Edition. December 2020. Available at DietaryGuidelines.gov
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8.7

Carbohydrate Recommendations- Summary

5.7 Carbohydrate Recommendations- Summary

In this chapter, you learned what carbohydrates are, the different types of carbohydrates in your diet, and that excess consumption of some types of carbohydrates cause disease while others decrease disease risk. Carbohydrate recommendations may vary from organization to organization. Throughout this course, we will focus on the guidelines given in the 2020-2025 Dietary Guidelines for Americans and the Dietary Reference Intakes (DRIs) published by the Food and Nutrition Board. General carbohydrate recommendations are summarized in Table 3.

	Carbohydrate Intake Recommendations
Total Carbohydrates (gm)	130 g/day: This is the minimum amount of carbohydrate recommended per day for proper neurological function. Most people need substantially more carbohydrate per day to sustain typical activity levels.
Carbohydrate as a Percentage of Calories (AMDR)	45-65% of total Calories (adults)
Added Sugars	Less than 10% of total Calories
Fiber	38 g/day (adult men), 25 g/day (adult women), or 14g/1000 calories
Type of Carbohydrate Intake	Make at least half of your grains a whole grain

Table 3: Recommended carbohydrate intake [2,14]

Dietary Fiber Recommendations

The adequate intake (AI) for Total Fiber is based on data which showed that 14 grams per 1000 Calories (14g/1000 Calories) reduced the risk of coronary heart disease.[15] Age and gender-specific AIs were set by taking 14 g/1000 Calories and multiplying it by the median energy intake for each group. For example, you will find that the Total Fiber AI on the DRI tables for adult men and adult women ages 19-50 is 38 g/day and 25 g/day, respectively. However, some diet analysis programs recommend individual Total Fiber intake based on the 14 g/1000 Calories and multiply it by the individual's recommended calorie intake. Either AI recommendation, the gender-specific age recommendation or the calorie-based recommendation, can be used and is helpful to ensure adequate consumption of fiber.[15]

It's the Whole Nutrient Package

In choosing dietary sources of carbohydrates, the best ones are those that are nutrient dense. This means they contain substantial amounts of essential nutrients per calorie of energy. In general, nutrient-dense carbohydrates are minimally processed and include whole-grain bread and cereals, low-fat dairy products, fruits, vegetables, and legumes (beans). In contrast, dietary carbohydrates that are not nutrient dense are often referred to as "empty-calorie" foods. They are highly processed and often contain added sugars and fats. Soda, cakes, cookies, and candy are examples of empty-calorie carbohydrates. Unfortunately, some products can masquerade as healthy, but contain a lot of added sugars. For example, many dairy products, granola bars and bread products contain substantial amounts of added sugars. Collectively, foods containing high amounts of added sugars are often referred to as 'bad carbohydrates,' as they are known to cause health problems when consumed in excess; but if eaten in moderation these types of products can still be included as part of a healthy diet.

Nonnutritive Sweeteners

Sweeteners can be sub-divided into two group: **nutritive** and **non-nutritive**.[16] Nutritive sweeteners contain carbohydrate and energy (usually 4 kcal/gram) and include the simple sugars that have already been discussed (mono and disaccharides in their various forms). The **sugar alcohols** (polyols) are also a type of nutritive sweetener that has not yet been touched on. They provide ~2 kcals/gram and have some physiological benefits when compared to the other nutritive sweeteners. For example, they have fewer calories per gram (2 verses 4 kcal/gram), they have a minimal effect on blood sugar levels (which may have benefits for individuals with diabetes), and they either don't cause cavities or may inhibit cavity production. The sugar alcohol "xylitol" has been promoted as actually being anti-cariogenic (or cavity preventing). Examples of the sugar alcohols are listed in Table 4.

Example of Sugar Alcohols	Relative Sweetness Compared to Sucrose
Sorbitol	50%-70%
Mannitol	50%-70%
Xylitol	100%
Erythritol	60%-80%
Lactitol	30%-40%
Malitol	90%

Example of Sugar Alcohols	Relative Sweetness Compared to Sucrose
Isomalt	45%-65%

Table 4: Some common sugar alcohols[17]

Because of their properties, they have been added to food products for many years as a means of decreasing amounts of added sugars while maintaining a certain level of sweetness. Sugar alcohols are useful, but they are not as sweet as other non-nutritive sweeteners and in some cases can cause gastrointestinal distress when used heavily. [15]

Nonnutritive sweeteners have taken the forefront in the market as an option to provide sweetness without the negative health effects of sugar. For example, nonnutritive sweeteners have little to no effect on blood sugar levels, they do not promote tooth decay and they make a lower contribution to total caloric intake. Generally, the nutritive sweeteners come from natural sources and the nonnutritive sweeteners are made by chemical methods. Exceptions to this rule are stevia and monk fruit (lua han gua extract) which are both extracted from plants. The nonnutritive sweeteners that are chemically produced (also called artificial sweeteners) have to be tested for safety and then approved by the FDA before they can be marketed in the United States. For each of the sweeteners an **Acceptable Daily Intake (ADI)** is also established. The ADI represents the amount of the sweetener (by body weight) that can be safely consumed every day over a lifetime without adverse effects.[16] The values are set with a generous safety factor. Some of the approved non-nutritive sweeteners and their ADI's are listed in Table 5. None of these sweeteners contain any appreciable calories.

Example of Non-Nutritive Sweeteners	Relative Sweetness compared to Sucrose	Acceptable Daily Intake (ADI)
Acesulfame K	200 x sweeter	15 mg/kg body weight
Aspartame	200 x sweeter	50 mg/kg body weight
Neotame	7000-1300 x sweeter	0.3 mg/kg body weight
Saccharin	200-700 x sweeter	15 mg/kg body weight
Stevia	200-400 x sweeter	4 mg/kg body weight
Sucralose	600 x sweeter	5 mg/kg body weight

Table 5: Some common non-nutritive sweeteners [16]

Because nonnutritive sweeteners contribute sweet taste but with greatly reduced calories compared to sugar, it seems logical to conclude that they might be a helpful tool for weight loss. However, research provides mixed results. The 2015-2020 Dietary Guidelines Advisory Committee states, "There is insufficient evidence to recommend the use of low-calorie sweeteners as a strategy for long-term weight loss and weight maintenance."

The use of non-nutritive sweeteners in the management of diabetes has provided options for those with this disease. It has allowed individuals with diabetes to enjoy sweet flavored products more often in a manner that allows better dietary control and overall diet quality. It is important to note that while these products do provide a sweet sensation, they do not provide all the textural qualities nutritive sweeteners provide.

Key Takeaways

- *The recommended intake for adults is 45-65% of total calories from carbohydrates, with a minimum of 130 grams per day for proper brain function.*
- *The recommended daily fiber intake is 38 grams for adult men and 25 grams for adult women.*
- *Nutrient-dense carbohydrates are minimally processed whole foods (e.g., whole grains, fruits), whereas "empty-calorie" foods are highly processed and contain added sugars and fats.*
- *Sweeteners are divided into nutritive (containing calories, like sugar alcohols) and nonnutritive (providing little to no calories, like stevia or sucralose).*
- *Nonnutritive sweeteners do no affect blood sugar or cause tooth decay, but research is mixed on whether they are an effective strategy for long-term weight loss.*

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9

Chapter 9: Protein

Chapter 6: Protein

Yea, flesh also of beasts and of the fowls of the air, I, the Lord, have ordained for the use of man with thanksgiving; nevertheless, they are to be used sparingly (D&C 89:12)

And whoso forbiddith to abstain from meats, that man should not eat the same, is not ordained of God. For, behold, the beasts of the field and the fowls of the air, and that which cometh of the earth, is ordained for the use of man for food. (D&C 49: 18-19)

Protein has many functions throughout the body. Its importance can be seen on a large scale because it serves a visible structural role in muscle, bone matrix and hair. Protein also has essential functions on a cellular level. Protein contains calories (4 kcal/gram), but mammals do not use substantial amounts of protein for energy because of protein's important structural and regulatory roles. Instead, it is used to fulfill other critical roles that are unique to protein.

9.1. Protein Food Sources

9.2. Amino Acids and Proteins

9.3. Protein Digestion and Absorption

9.4. Protein Synthesis

9.5. Protein Turnover

9.6. Functions of Proteins
9.7. Protein Undernutrition
9.8. Protein Recommendations
9.9. Protein Quality
9.10. Protein Choices

9.1

Protein Food Sources

6.1 Protein Food Sources



Meat Protein. Free to use under the Unsplash License. Photo by Cindie Hansen on Unsplash.

Dietary protein intake is necessary to sustain life. It is found in a wide variety of foods. The most commonly identified protein sources are meat, poultry, fish, and dairy products. These foods are rich sources of protein. Some plant foods are also high in protein such as legumes like kidney, pinto, black beans and dried peas and lentils. Nuts and seeds can also be a good sources of protein. Some people are surprised to find that most grains also contain a modest amount of protein and most vegetables contribute some protein to our diet as well. The only food group that typically provides little protein is the fruit group.

Even though plant protein sources are generally less protein-dense than animal protein sources, most of the protein intake throughout the world comes from plant sources. It is estimated that 57% of the world's protein intake comes from plants, 18% from meat, 10% from dairy, 6% from fish and shellfish, and 9% from other sources.[1] Animal protein sources are expensive and are not as accessible in many areas of the world. Wheat, corn, and rice are the most commonly used grains. In West Africa and India, the grain "millet" is widely used, and in Ethiopia "teff" is popular. These become key protein sources because of the



Millet. Photo by Efraimstochter via Pixabay.

volume of grains that are consumed worldwide.[1] The most commonly consumed animal protein comes from domesticated animals

such as pigs, poultry, sheep, goat, cattle, and buffalo. Pork consumption is estimated to be about 36% of the world's meat supply and poultry 35%. The type of poultry consumed is predominately chicken, but other sources include turkey, duck, goose and guinea fowl. The type of meat consumed can sometimes be regionally unique. For example, guinea pig is a popular delicacy in Peru. Camels, yaks, horses, and ostriches are examples of some other regionally unique meat sources. Local game animals and sometimes exotic animals such as alligator and snakes can also be a dietary protein source.[2] Fish and other seafood are important contributors to protein intake in many places. Fish can be produced with much less food input than other animal protein sources such as beef. Aquaculture (fish farming) is expected to be the major supplier of fish by 2030.[2]

By 2050 it is expected that the world population will be close to 10 billion people. This will be an increase of almost 3 billion additional mouths to feed. How that demand will be met, and how adequate protein will be supplied is a concern. An increased emphasis on the use of legumes and lentils is a viable consideration. They are high in protein and other essential nutrients

Vegetable protein sources from marine sources such as algae and seaweed could be utilized more fully. More emphasis on animal protein sources that require lower amounts of space and resources for production such as chicken and rabbits may



Tilapia ponds in Ghana, Africa.



Insects are a protein source in most of the world: Meal worms and crickets. Photo by SadiaK123 via Pixabay.



Insects are a protein source in most of the world. Photo by kai62 via Pixabay.

be considered. The production practicality of synthetic meat products is currently being investigated. Such products have already been approved for retail sale. Ongoing technological advances will increase our ability to maximize production efficiency (more animal and plant protein production with less needed space and resources). An interesting alternative source of protein that is commonly used in Asia, Africa and South America is insect protein. More than 2 billion people consume insects as a common part of their diet. Roughly 31% of the insects consumed are beetles. Caterpillars are the next most common at 18%. Bees, wasps and ants make up 14%, and grasshoppers, locust and crickets 13%. The remaining come from other insects such as cicadas, leafhoppers, termites and dragonflies[1,3.] The consumption of insects as food is referred to as entomophagy. While insects are not widely accepted as a protein source in the United States, they are generally high in nutrients, environmentally friendly to produce and a cost-efficient source of protein. With an expected increase in the cost of meat over the next 30 years, an increased use of insects as a protein source is an interesting consideration.[3]

This chapter will explore the chemical composition of proteins, how proteins are made and what they do in the body. We will then look at the similarities and differences between plant and animal proteins. We will also review how to determine daily protein recommendations and ways to get an adequate intake from foods.

Key Takeaways

- *Protein is found in a wide variety of foods, including animal sources like meat and dairy, and plant sources like legumes, nuts, seeds, and grains.*
- *Globally, over half of the world's protein intake comes from plant sources, with grains being the most commonly consumed due to their accessibility.*
- *There is a challenge of providing adequate protein for a growing world population and points to potential solutions.*
- *More efficient protein sources are being considered to meet future demand, including increased use of legumes, and alternative animal proteins like chicken and farmed fish.*
- *A significant portion of the world's population (over 2 billion people) already consumes insects, which are a nutrient-rich, environmentally friendly, and cost-effective protein source.*

References (see below)

- 1. Future protein supply and demand: strategies and factors influencing a sustainable equilibrium (2017). Foods Jul; 6(7): 53
- 2. Food and Agricultural Organization of the United Nations (June 3rd, 2021). Agriculture and Consumer Protection Department, Animal Production and Health. http://www.fao.org/ag/againfo/themes/en/meat/backgr_sources.html
- 3. Huis AV. Potential of insects as food and feed in assuring food security. Annu. Rev. Entomol. 2013; 58: 563-583.

9.2

Amino Acids and Proteins

6.2 Amino Acids and Proteins

Amino Acids



Meats, nuts, eggs, and other protein sources. Image by Smastronardo under CC BY-SA 4.0 license.

Amino acids are the building blocks of protein. This can be illustrated using a beaded necklace analogy. The beaded necklace represents a protein, and the individual beads represent amino acids. Accordingly, to understand protein, a person first has to understand amino acids.

Amino acids are composed of the elements carbon, hydrogen, oxygen, and nitrogen. Each amino acid consists of a central carbon atom connected to a side chain, a hydrogen, a nitrogen-containing **amino**

group, and a carboxylic **acid** group—hence the name “amino acid.” All amino acids contain these four basic features. The arrangement of the amine group, the acid group and the hydrogen around the carbon center is the same for all amino acids (see Figure 6.1). Only the side chain (R) differs between amino acids. There are 20 different amino acids commonly used in building proteins. With deductive reasoning the conclusion can then be drawn that there are 20 different R groups, which is correct!

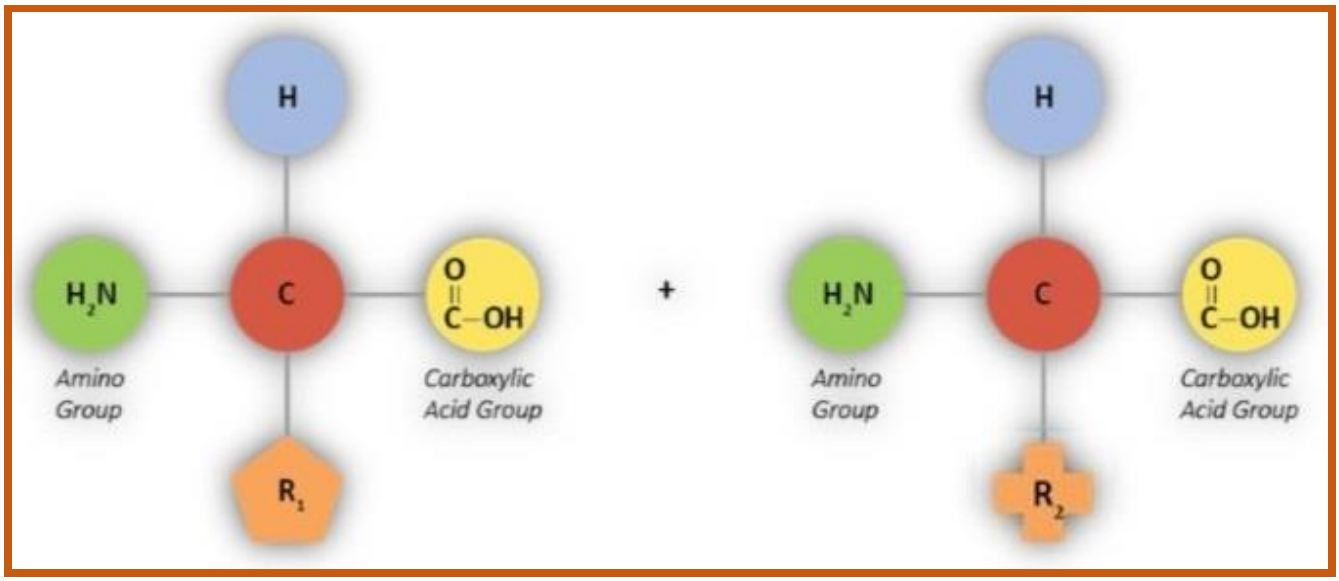


Figure 6.1: Structure of an amino acid

Types of Amino Acids

There are 20 different amino acids that are used to make proteins. If you consider the length of most proteins (hundreds of amino acids long) and the number of possible combinations that can be created with 20 different amino acids, it is apparent why every protein produced in the body can have a unique structure. Of these 20 amino acids, only 9 are considered essential (required to be consumed in the diet.) The other 11 amino acids can be produced by the body from other substances and are therefore considered non-essential. The **essential and non-essential amino acids** are listed in Figure 6.2.

Essential Amino Acids	Non-Essential Amino Acids
Histidine	Alanine
Isoleucine	Arginine
Leucine	Asparagine
Lysine	Aspartic Acid
Methionine	Cysteine
Phenylalanine	Glutamic Acid
Threonine	Glutamine
Tryptophan	Glycine
Valine	Proline
	Serine

Essential Amino Acids	Non-Essential Amino Acids
	Tyrosine

Figure 6.2: Amino acids

In order for the body to make the non-essential amino acids, a source of nitrogen is needed. One of the key ways proteins differ structurally from carbohydrates and fats is they contain nitrogen in their structure. One of the sources for non-essential amino acid production can be fat or carbohydrate. For example, the amino acid glutamine is a non-essential amino acid. It can be made from part of the monosaccharide "glucose" when the body needs it. However, a critical limitation is that glucose does not contain nitrogen. To complete the non-essential amino acid, the needed nitrogen will be transferred from another source through a process called ***transamination****. Often the source of nitrogen will be another amino acid that is plentiful in the body at that time.*

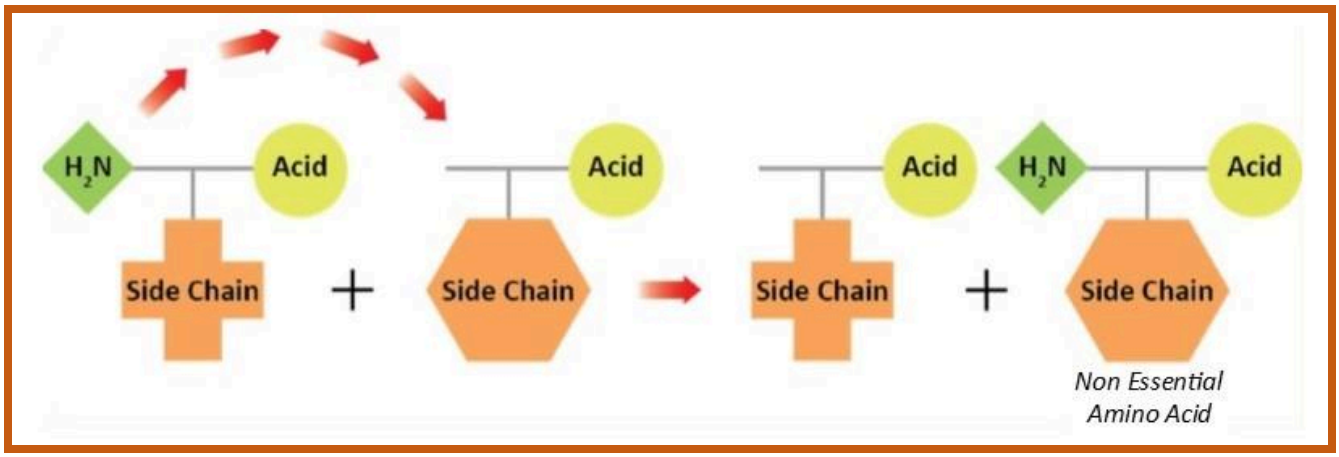


Figure 6.3: Transamination

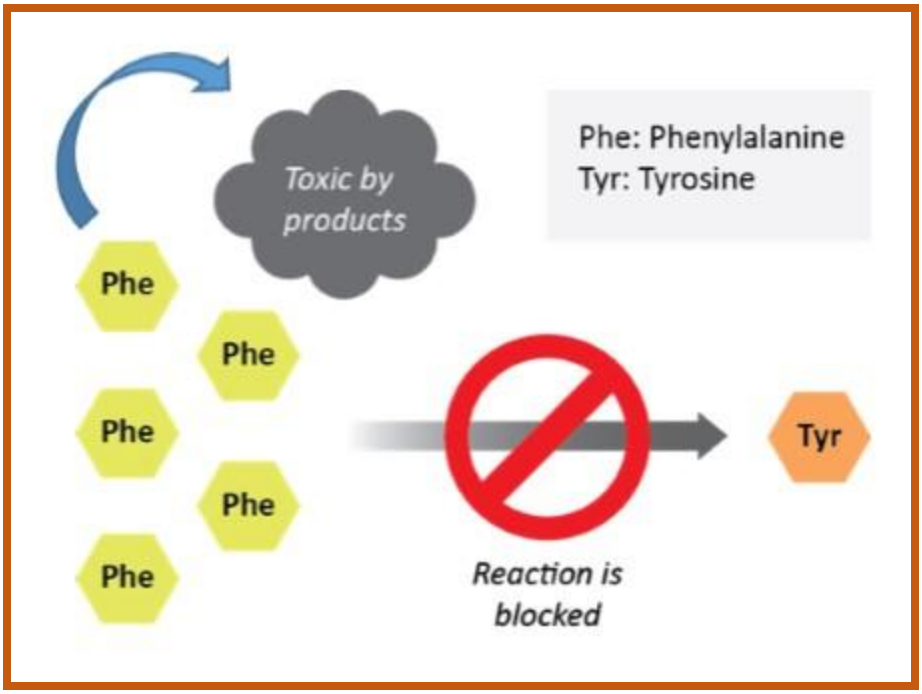


Figure 6.4: Conversion of phenylalanine to tyrosine is blocked in PKU

Under special circumstances, some non-essential amino acids can become essential amino acids. These unique amino acids are referred to as **conditionally essential amino acids.** A classic example of this is the genetic disease phenylketonuria **(PKU)**. This genetic disorder is caused by an error in the DNA. This error prevents the production of an enzyme needed to convert phenylalanine (an essential amino acid) to tyrosine (a non-essential amino acid). Tyrosine is a non-essential amino acid because it can be made from phenylalanine. When people have this genetic error, they cannot break down the amino acid phenylalanine or produce tyrosine (see Figure 6.4). Tyrosine now becomes an essential amino acid since the body cannot make it from phenylalanine due to the missing enzyme.

Even though phenylalanine is an essential amino acid, individuals with PKU end up with too much phenylalanine. The excess phenylalanine is converted to secondary products (toxic byproducts) that are harmful to the body. Untreated PKU will lead to seizures and poor intellectual development. Treatment for PKU includes a specialized diet that restricts phenylalanine along with the consumption of a special formula that includes essential amino acids.[4]

Peptide Bonds

Proteins are constructed by linking amino acids together in a chain, similar to the beads on a necklace. The beads (amino acids) are held together by bonds. The bonds between amino acids are called **peptide bonds**. Peptide bonds are formed between the acid and the amine group with the removal of water (see Figure 6.5). Two amino acids form a **dipeptide**, three amino acids form a **tripeptide**, and several amino acids bonded together form a **polypeptide**.

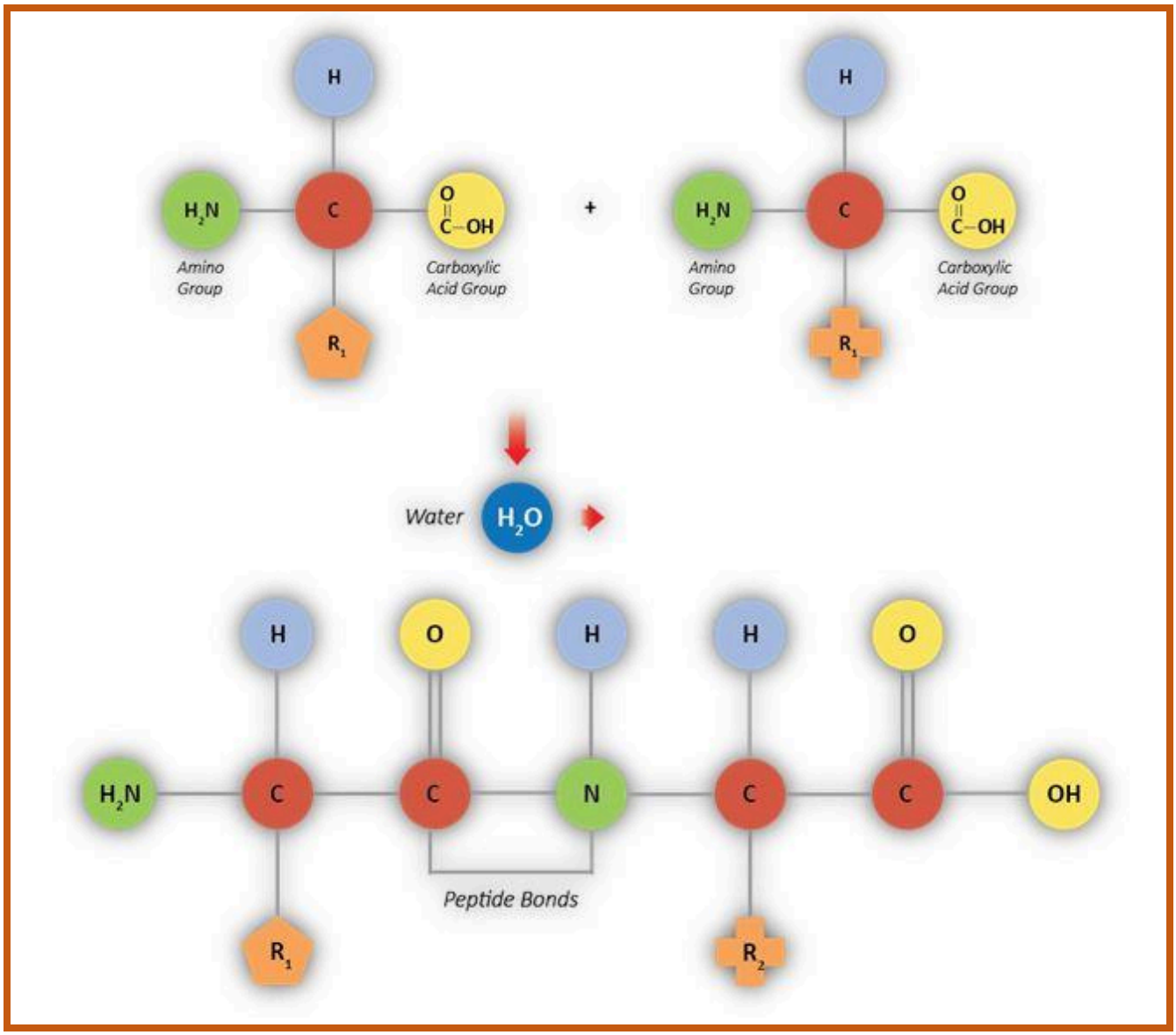


Figure 6.5: Formation of a peptide bond

Protein Folding

Once a protein is formed the protein will fold into a functional shape. After a protein is made, chemical and structural forces will ensure that it will fold into the same shape every time. The proteins shape is essential for it to function properly.

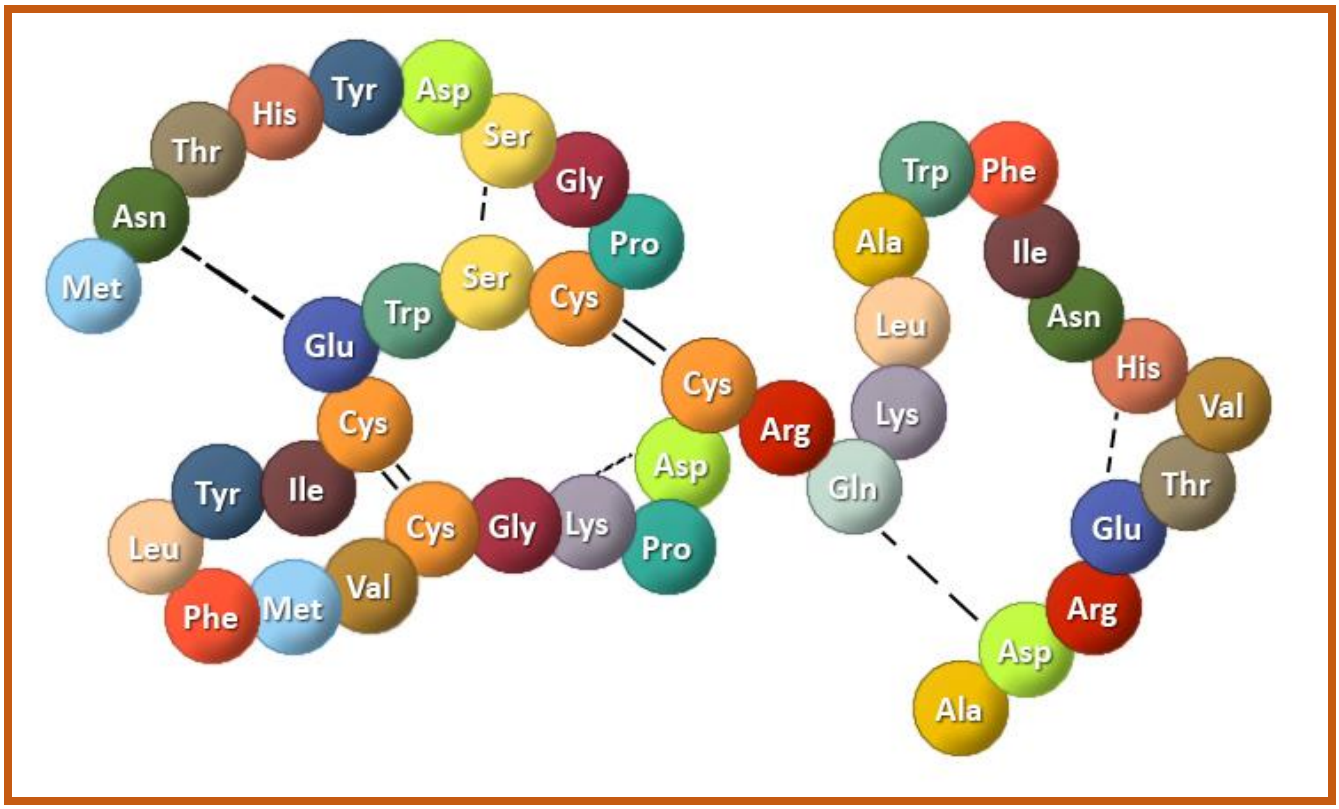


Figure 6.6: Folded protein

When a protein unfolds it can no longer function properly. The unfolding process is referred to as denaturation. Forces that can cause a protein to denature include: heat, change in acid-base balance, alcohol, and physical force. For example, when the digestive enzyme amylase enters the stomach it is denatured by the stomach acid and will no longer break down starch. If important body proteins become denatured, harm can occur to the body. Examples are illness that may cause a high grade fever or a change in body pH.

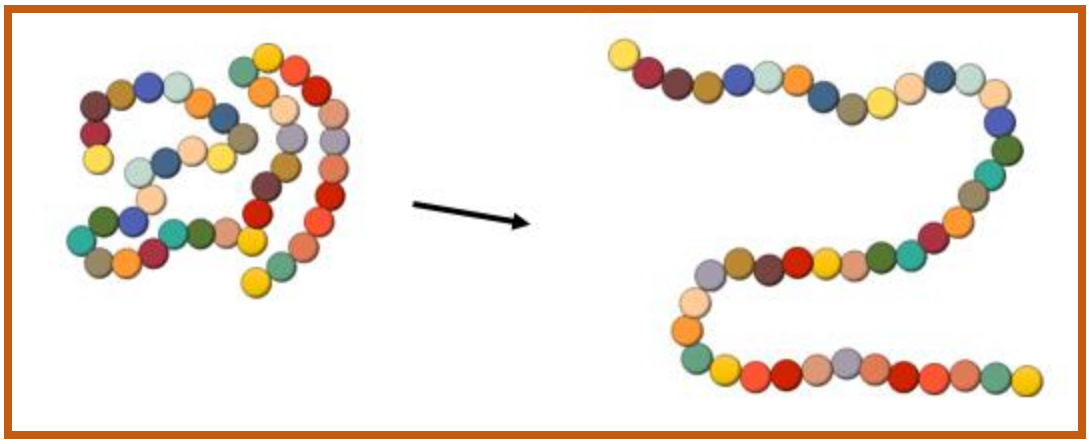


Figure 6.7: Denaturation

Typically, we don't want our body proteins to denature because they will not be able to function correctly. But when protein is eaten in food, protein denaturation by the acid in our stomach is necessary for proper digestion and absorption of the food protein.

Protein denaturation can also occur when cooking proteins before consumption. Whether we recognize it or not most of us have seen this process in action. When a raw egg is cracked into a hot pan, the egg white is initially clear, but quickly starts to turn opaque. With exposure to heat, the proteins in the egg white unfold and the denatured proteins link together. Light can no longer penetrate the egg white, and it is no longer transparent. The denaturation of proteins during cooking has no impact on the nutritional value of the protein and can create pleasing textural qualities. Protein denaturation can be positive or negative depending on the circumstances.

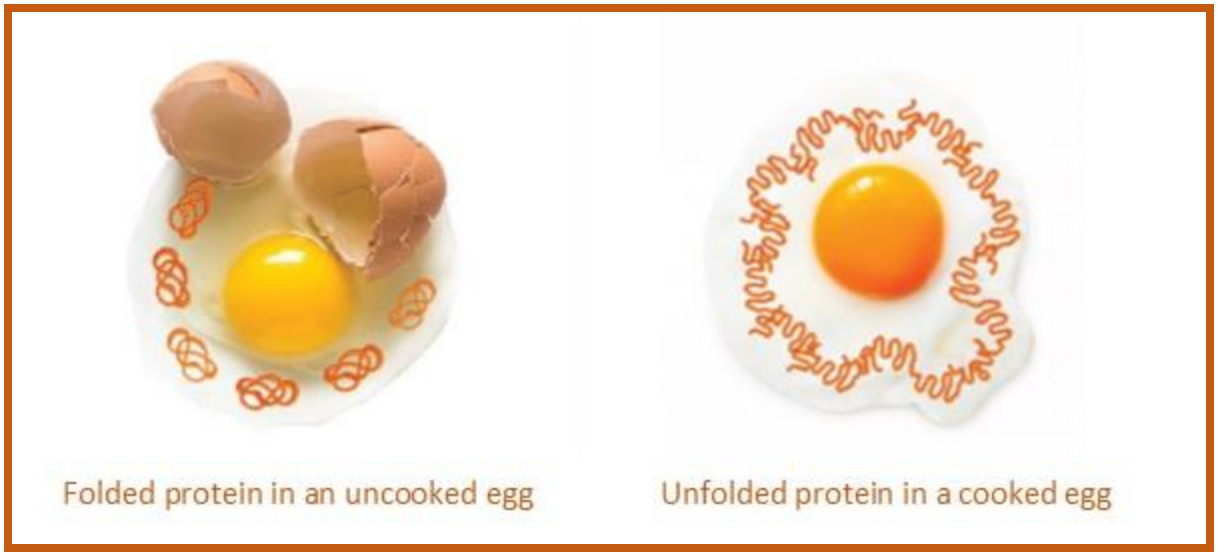


Figure 6.8: Denaturation in the cooking process of an egg

Key Takeaways

- *Amino acids are the building blocks of protein, and their unique side chain (R group) distinguishes the 20 different types.*
- *Of these 20 amino acids, 9 are considered essential (must be consumed in the diet), while the other 11 are non-essential (the body can produce them).*
- *Amino acids are linked together by peptide bonds to form a chain, which then folds into a specific, functional three-dimensional shape.*
- *Denaturation is the process where a protein loses its shape and function due to forces like heat, alcohol, or changes in pH.*
- *Protein denaturation is necessary for the digestion of food but can be harmful if it affects essential body proteins.*

Reference (see below)

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9.3

Protein Digestion and Absorption

6.3 Protein Digestion and Absorption

In order to be absorbed, proteins need to be broken down. The body can absorb single amino acids, dipeptides, or tripeptides. Typically, nothing larger than a tripeptide is safely absorbed. In the mouth, large protein pieces can be mechanically separated through chewing, but the chemical digestion (breaking of peptide bonds) of protein begins in the stomach. The stomach releases gastric juices containing hydrochloric acid and the enzyme pepsin, which initiate the breakdown of the protein. The acidity of the stomach facilitates the unfolding of the proteins (denaturation). Pepsin, which is secreted by the cells that line the stomach, dismantles the protein chains into smaller and smaller fragments by breaking the peptide bonds (see Figure 6.9).

Although the chemical digestion of protein begins in the stomach, the majority of the digestion occurs in the small intestine. The pancreas secretes digestive juices that contain the enzymes trypsin and chymotrypsin that continues the chemical digestion of protein in the small intestine. The cells that line the small intestine (brush border cells) release other enzymes that finalize the process by breaking the small protein fragments into the individual amino acids, dipeptides, and tripeptides. The muscle contractions of the small intestine mix and propel the digested proteins to the absorption sites. In the lower parts of the small intestine, the amino acids are transported from the intestinal lumen into the intestinal cells to the blood. Once the amino acids are in the blood, they are transported to the liver. As with other macronutrients, the distribution of amino acids to other body locations is regulated by the liver.

Key Takeaways

- *The body can only absorb very small protein fragments, specifically single amino acids, dipeptides, or tripeptides.*
- *Chemical digestion of protein beings in the stomach, where hydrochloric acid denatures proteins and the enzyme pepsin begins breaking down peptide bonds.*
- *The majority of protein digestion occurs in the small intestine with the help of enzymes from the pancreas and the intestinal lining.*

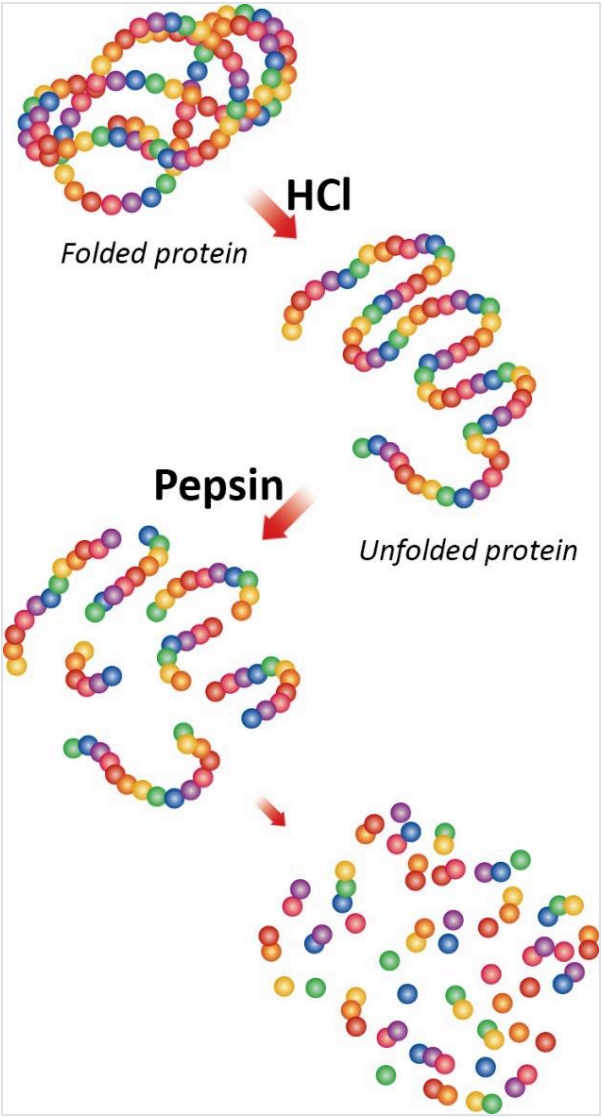


Figure 6.9: Action of Pepsin

- *Once broken down, amino acids and small peptides are absorbed into the bloodstream and are transported to the liver for regulation and distribution.*

Reference (see below)

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9.4

Protein Synthesis

6.4 Protein Synthesis

Once the proteins are digested and the amino acids are absorbed, the cells throughout the body will use the amino acids to build proteins necessary for cellular function. The building of a protein consists of a complex series of reactions that can be summarized into three basic processes: transcription, translation, and protein folding.

The information to build every protein needed by the human body is contained in the DNA. Every cell of the body has a copy of this information in its nucleus. When a particular protein is needed, the part of the DNA that contains the instructions to build the protein of interest is copied. In order for the copy to be made, the segment of the DNA that contains the pertinent information is unzipped so it can be read. The process of copying the DNA is called **transcription**. The copy of the DNA segment is called messenger RNA (mRNA).

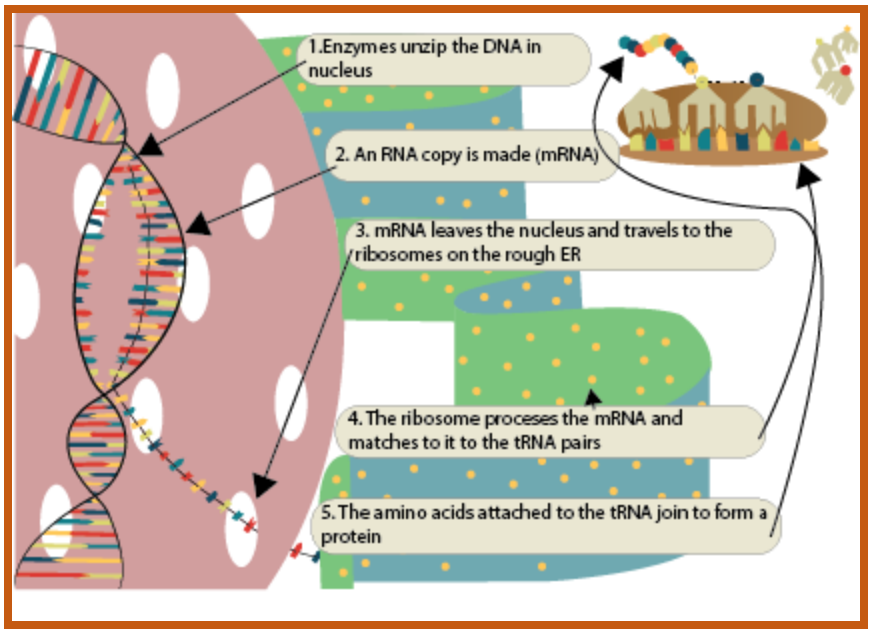


Figure 6.10: Protein synthesis

The mRNA leaves the nucleus and enters the cytoplasm of the cell where proteins called **ribosomes** (these are usually anchored on the endoplasmic reticulum) read the information contained in the structure of the mRNA and construct the appropriate protein. The specific order of the amino acids in the new protein is important. If an error exists in the order of the amino acids, significant health issues can occur. Cystic fibrosis, hemochromatosis, and phenylketonuria are a few examples of diseases caused by an error in the DNA sequence.

The process of constructing a protein is called **translation**. As mentioned earlier, the amino acids are connected together using special bonds called peptide bonds. Transfer RNA (tRNA) bring the needed amino acids to the ribosomes where they are then bonded together in the correct sequence. Every protein in the body has its own distinctive sequence of amino acids. As a result, the unique chemical and structural forces in action within that protein result in a unique folding structure that is consistent each time that protein is made.

Key Takeaways

- *Protein synthesis is a complex process that uses amino acids to build proteins and is summarized into three main processes: transcription, translation, and protein folding.*
- *Transcription is the first step, where the instructions to build a protein are copied from DNA in the cell's nucleus to create a messenger RNA (mRNA) molecule.*
- *Translation is the second step, where the mRNA leaves the nucleus and is read by ribosomes to assemble the amino acids in the correct sequence.*
- *The specific order of amino acids is crucial for a protein's function, and an error in this sequence can cause serious health issues.*
- *The final step is protein folding, where the protein assumes a unique, functional shape that is essential for its role in the body.*

Reference (see below)

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9.5

Protein Turnover

6.5 Protein Turnover

Just as some plastics can be recycled to make new products, amino acids are recycled to make new proteins. All cells in the body continually break down proteins and build new ones, a process referred to as protein turnover. Every day the breaking down and building of proteins account for about 10-25% of the energy we expend at rest.[5] To form these new proteins, amino acids from food and those from body protein breakdown are placed into an "amino acid pool" (see Figure 6.11).

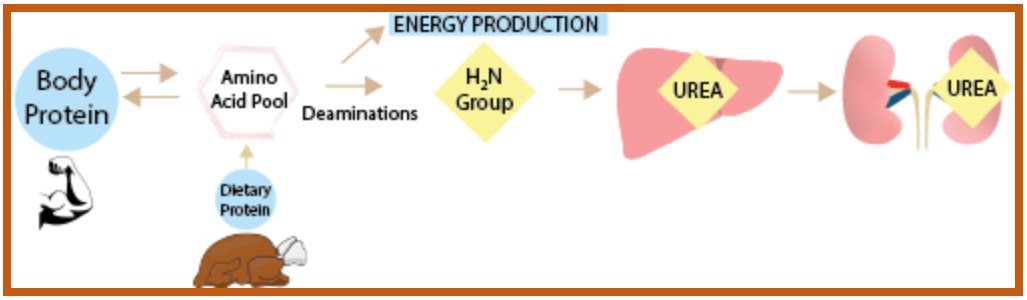


Figure 6.11: Amino acid pool. ***NEEDs New Image.*** *Liver image by Cancer Research UK / Wikimedia Commons under CC BY-SA 4.0 license with edits. Arm image on Clipart Library. Turkey Image by cugur1978 via pixabay.*

The amino acid pool is a term used to describe amino acids that are free to be used throughout the body. When an amino acid is needed to build a protein, it can be taken from this pool of available amino acids. The amino acid pool accounts for less than one percent of total body protein content. It is not big enough to be considered a storage reserve of protein, so a consistent intake of good quality protein is still important for optimal health. Amino acids are primarily used to build proteins. They are also needed to build other nitrogen-containing compounds, such as DNA and RNA. To some extent, amino acids can be used to produce energy.

The fraction of protein that is used for energy (typically about 5% of the protein that is taken in) has to be prepared before it can be metabolized for energy within cells. The body's energy extraction systems are geared to handle carbohydrate and fat. As emphasized several times, proteins are mostly made from the same materials as carbohydrate and fat (carbon, hydrogen and oxygen), but they also contain nitrogen. That amino or nitrogen group (in the form of ammonia) must be removed before the amino acids in the proteins can be turned into usable

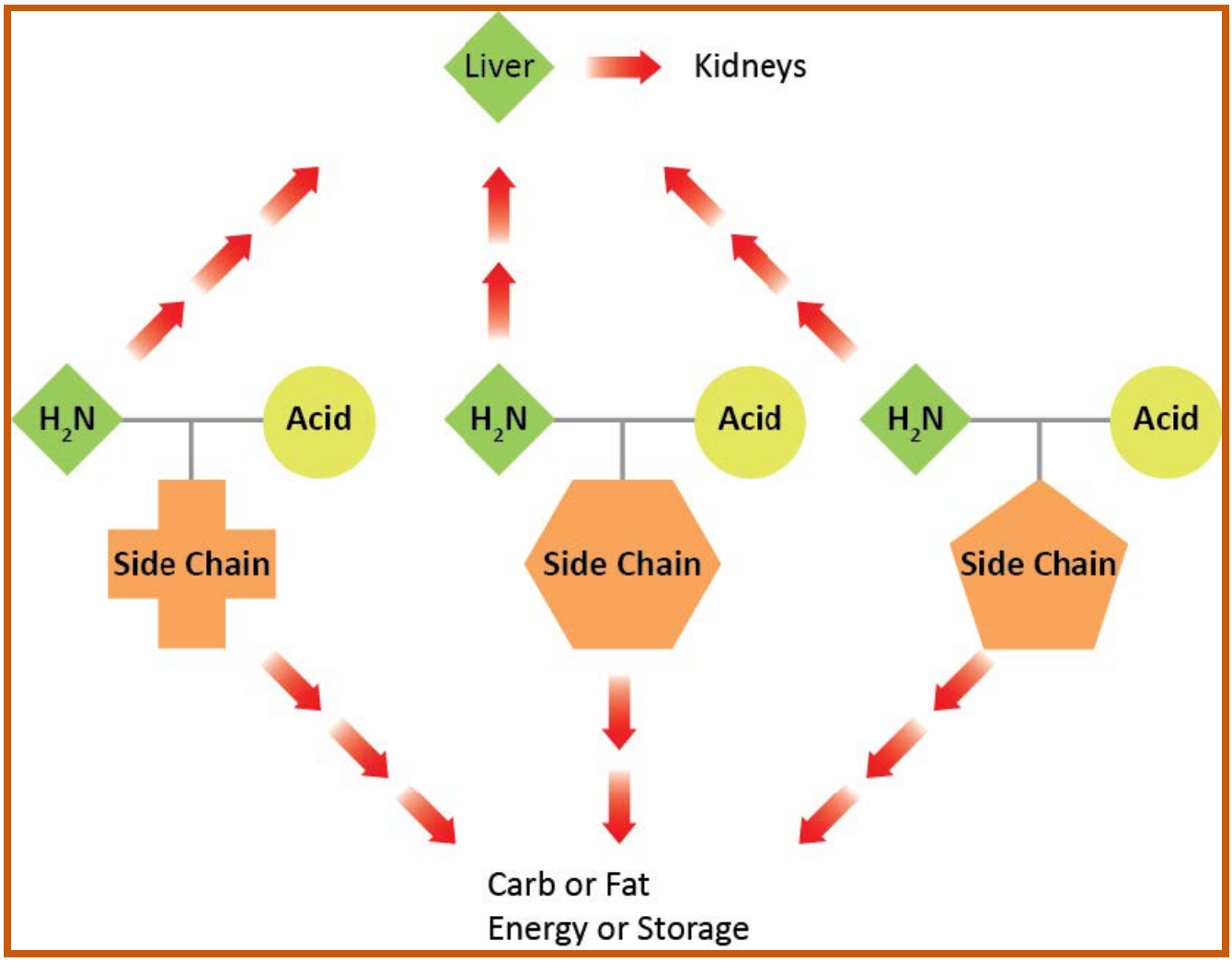


Figure 6.12: A closer look at deamination

energy (ATP). The removal of the amino or nitrogen group from the amino acids is called **deamination**. The liver processes the amino or nitrogen group (ammonia) into **urea**. The urea is then released into the blood. The kidneys filter urea out of the blood and excrete it in the urine. The use of protein for energy increases when other energy sources are lacking. This might occur during starvation or lengthy rigorous exercise. Under these circumstances. the body must use muscle tissue to supply the needed protein. During periods of high protein intake, protein use for energy also increases. In these circumstances, adequate fluid consumption is encouraged to allow the kidneys to handle all the urea produced from the increased protein metabolism.

Key Takeaways

- *Protein turnover is the continuous process of the body breaking down old proteins and building new ones from a pool of amino acids.*
- *The amino acid pool is a collection of free amino acids from both food and body protein breakdown, which are available to build new proteins but are not a long-term storage reserve.*
- *When amino acids are used for energy, the nitrogen-containing amino group must first be removed in a process call deamination.*

- *The liver converts the removed nitrogen group into urea, which is then filtered from the blood by the kidneys and excreted in urine.*
- *the body uses protein for energy when other energy sources are lacking or when protein intake is very high.*

Reference (see below)

- 5. Welle S, Nair K. Relationship of resting metabolic rate to body composition and protein turnover. Am J Physiol. 1990; 258: 990-98.

9.6

Functions of Proteins

6.6 Functions of Proteins

Proteins play a variety of roles in the body, including structural, regulatory and energy production.

Structure

More than one hundred different **structural proteins** have been discovered in the human body. Structural proteins are needed in just about every tissue in the body. One of the most abundant is collagen, which makes up about 1/3 of all body protein.[6] Collagen makes up 30 percent of bone tissue and comprises a large part of tendons, ligaments, cartilage, skin, and muscle. Collagen is a strong, fibrous protein. 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 the skin allow it to go back to its original shape. Another strong, fibrous protein is keratin, which is what skin, hair, and nails are made of. Vitamin C is important in collagen formation and vitamin A impacts keratin production. The devastating effect of deficiencies of these vitamins will be discussed more fully later.

Regulation

Proteins regulate body processes in a variety of ways. **Enzymes** are proteins that assist chemical reactions. An enzyme provides a site for a chemical reaction to happen (this is known as "catalysis"-see Figure 6.13). **Hormones** can also be made of protein. Hormones are chemical messengers that direct cellular process. Insulin, a hormone that regulates blood glucose levels, is a good example of a protein based hormone.

Proteins also play a role in managing the body's fluid and acid-base balance. A protein in the blood called albumin helps keep water in the blood vessels, so it does not leak out into the tissues. Protein malnutrition can cause low blood albumin levels, which in turn can cause excess fluid to go into the tissues. The excess accumulation of fluid in the tissues is called **edema**.



Edema in the feet. *Photo by Ryaninuk under CC BY-SA 4.0 license.*

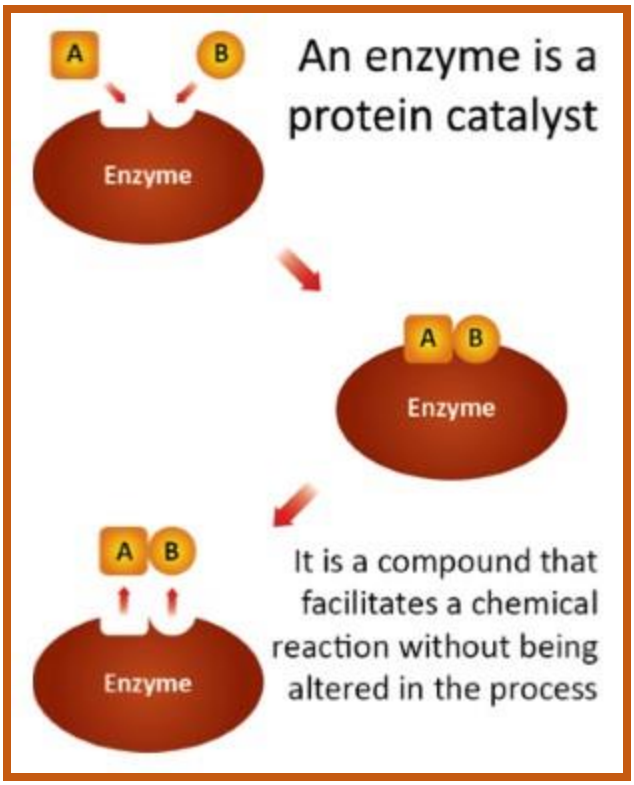


Figure 6.13: Function of an enzyme

Most chemical reactions in the body will occur only in a narrow range of pH (a measure of how acidic or basic something is). Proteins act to prevent changes in body pH levels, in this role they are referred to as **buffers**.

Most of the **transporters** that move nutrients and waste products in and out of cells and throughout the body are proteins. The immune system's attack and destroy functions that protect our bodies from harmful invaders are dependent on enzymes and **antibodies**, which are also proteins. Proteins are important!

Energy Production

Protein provides 4 Calories per gram. The body prefers to use lipid and carbohydrate as its primary energy sources but does burn a little bit of protein for energy each day. Under certain circumstances the amount of protein used for energy will increase. Typically, this would occur when other energy sources are lacking such as during starvation or long bouts of exercise, or simply when more protein is eaten, more protein is used for energy. Part of the broken-down protein can also be turned into glucose. The central nervous system can only use glucose for energy. When glucose is in short supply (like during a period of starvation, or at the end of exhausting bouts of exercise) protein is broken down. Through the process of gluconeogenesis in the liver, some of the amino acids are converted to glucose. This will supply the needed glucose for the central nervous system.

Key Takeaways

- *Proteins provide structural support for the body, with key examples being collagen (found in bones, skin, and tendons) and keratin (found in hair and nails).*
- *They have important regulatory functions, acting as enzymes to facilitate chemical reactions and as hormones (like insulin) to send chemical messages.*
- *Proteins also help maintain the body's fluid balance, and their role as buffers prevents harmful changes in pH levels.*
- *While not the primary energy sources, protein can be used for energy, providing 4 Calories per gram. Its use for energy increases during starvation or prolonged exercise.*
- *When other energy sources are low, protein can be converted to glucose through gluconeogenesis to supply the central nervous system, which relies on glucose for fuel.*

Reference (see below)

- 6. Shoulders M, Rains R. Collagen Structure and Stability. Annu Rev Biochem. 2009; 78: 929–958.

9.7

Protein Undernutrition

6.7 Protein Undernutrition

Protein undernutrition is a consequence of inadequate consumption of dietary protein. Understanding the functions of protein leads to an understanding of the characteristics of chronic protein deficiency. Low protein diets negatively impact immunity, growth, development, fluid balance and many other body processes. Two manifestations of severe protein deficiency are kwashiorkor and marasmus. Both are conditions of insufficient protein and calorie intake, with each having distinct characteristics.[7]

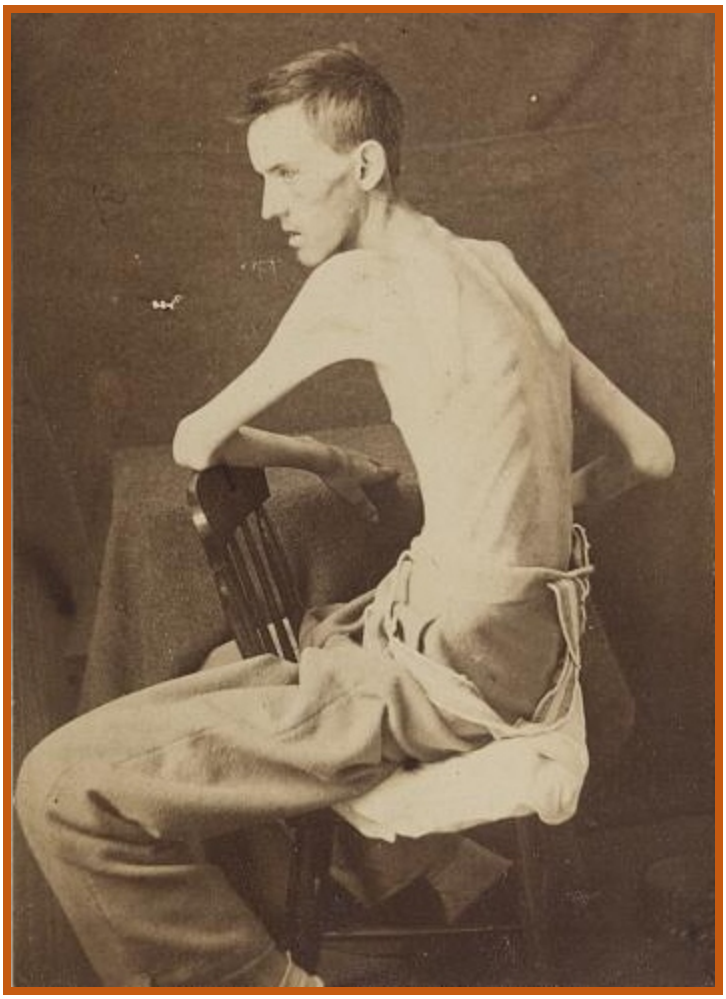
Kwashiorkor

Kwashiorkor comes from a language of Ghana. It means "disease of deposed child." Deposed child refers to a child who is no longer being breastfed because of the birth of a new baby.[7] In place of breast milk, the child is fed a watery, low protein, but adequate calorie porridge made from grain. Kwashiorkor is caused by a deficiency in dietary protein. It is characterized by swelling (edema) of the feet and abdomen, poor skin health, growth retardation, low muscle mass, and liver malfunction. In kwashiorkor, the child does not appear dramatically thin because enough calories are consumed to prevent muscle wasting.

Marasmus

Marasmus comes from a Greek word meaning "withering" or "to waste away." Marasmus is a severe deficiency of both protein and calories over an extended period of time. Starvation is another name for marasmus.

Marasmus is characterized by an extremely thin or "wasted" appearance because both muscle and fat stores have been depleted to meet the basic needs of the body. Other symptoms include poor skin health, growth retardation, fatigue, hunger and diarrhea. Marasmus is most likely to occur in areas of the world where food is chronically scarce due to entrenched poverty, famine or civil unrest. It can occur in people of any age. However, the statistics for children are grim. A 2020 World Health Organization reported that world-wide, 47 million children under the age of 5 are "wasted" and 14.3 million are "severely wasted."[8] Children under the age of one may be so severely wasted that their body weight may be as much as 60 percent less than that of a normal child of the same age.[9]



Man with marasmus. Image by Unknown author from the Library of Congress.

Marasmus is seen to a much lesser degree in affluent areas of the world. It is usually associated with severe illness (cancer or end stage dementia) and anorexia nervosa.

Key Takeaways

- *Protein undernutrition can have negative impacts on immunity, growth, and fluid balance.*
- *Kwashiorkor is a type of protein deficiency caused by a diet that ais low in protein but has adequate calories, and it is characterized by swelling (edema) of the feet and abdomen.*
- *Marasmus is a severe deficiency of both protein and calories, leading to an extremely thin and "wasted" appearance as both muscle and fat stores are depleted.*
- *While both are forms of malnutrition, Kwashiorkor is distinguished by edema, whereas Marasmus is characterized by severe wasting.*

References (see below)

- 7. Stanton J. Listening to the Ga: Cicely Williams' Discovery of Kwashiorkor on the Gold Coast. Clio Med. 2001; 71: 149–171.

- 8. World Health Organization. “Malnutrition.” April 2020. https://www.who.int/news-room/fact-sheets/detail/malnutrition
- 9. Titi-Lartey, O.A., Gupta, V. Marasmum. Treasure Island, Florida. StatPearls LLC, 2020 Accessed at https://www.ncbi.nlm.nih.gov/books/NBK559224/

9.8

Protein Recommendations

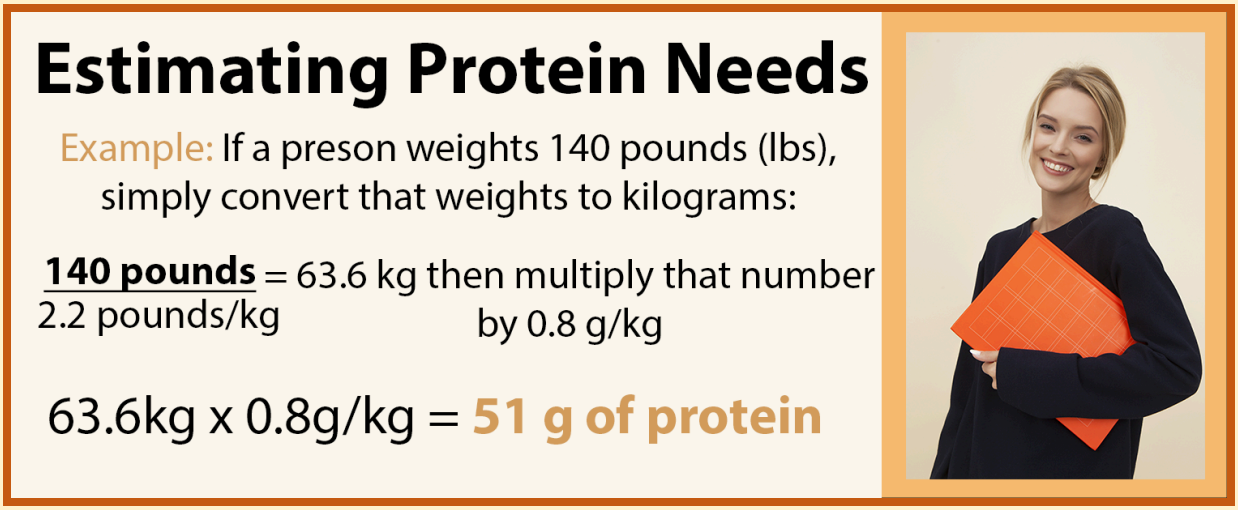
6.8 Protein Recommendations

Throughout this course, we will focus on the guidelines given in the 2020-2025 Dietary Guidelines for Americans and the Dietary Reference Intakes (DRIs) published by the Food and Nutrition Board. General protein recommendations are summarized in Table 1.

	Protein Intake Recommendations
Protein RDA	0.8 grams protein per kilogram body weight (adult)
Protein as a Percentage of Calories	10-35% of total Calories (adults)
Type of Protein Intake	Consume a variety of protein foods, including seafood, lean meats and poultry, eggs, legumes (beans and peas), and nuts, seeds, and soy products

Table 1: Recommended protein intake

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 protein balance. How much protein goes into a person is pretty easy to track; a simple dietary intake can determine this. But how much protein is used in the body is harder to track. The presence of nitrogen is the element that sets protein apart from the other macronutrients. When proteins are broken down and amino acids are catabolized, nitrogen is released, turned into urea by the liver, and excreted in the urine. By collecting the urine and looking at the nitrogen content, the amount of protein lost from the body can be estimated. The protein RDA, therefore, is the amount of protein recommended for a person to consume in their diet to balance the amount of protein lost. For healthy adults, this amount of protein was determined to be 0.8 grams of protein per kilogram of body weight. You can calculate your exact recommended protein intake per day based on your weight by using the following equation:



Estimating Protein Needs

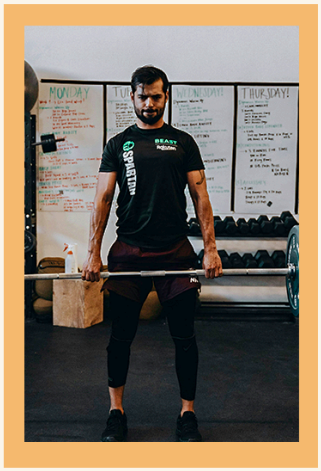
Example: If a person weighs 140 pounds (lbs), simply convert that weight to kilograms:

140 lbs = 63.6 kg then multiply that number by 0.8 g/kg

2.2 lbs/kg

63.6 kg x 0.8 g/kg = **51 g of protein per day**

A person is in a state of protein balance when protein input equals the amount of protein lost (as determined by the amount of nitrogen lost from the body). A person is in negative protein balance when the amount of nitrogen lost is greater than the amount consumed in protein foods. Negative protein balance means that the body is losing more protein than is being consumed. This state of imbalance can occur in people who have certain diseases such as cancer or muscular dystrophy. In these diseases, muscle protein breakdown can exceed protein intakes. Positive protein balance occurs when a person intakes more nitrogen from protein foods than is being lost. Positive protein balance occurs during periods of active muscle tissue growth such as pregnancy, child and adolescent development and athletic training.



Positive Protein Balance +

Gaining Musscle Tissue



Balanced



- Negative Protein Balance

Losing Musscle Tissue

Protein for Performance

Regular, rigorous physical activity increases a person's protein needs. Exact requirements are dependent on a variety of factors including the type of activity, intensity of the activity, frequency of exercise, training level, calorie and carbohydrate intake and food choices. Instead of 0.8 g/kg it is suggested that intake levels between 1.2-2.0 g/kg per day will meet athletic needs .[10] It is expected that protein recommendations for any athlete will change regularly based on their training cycle and should be adjusted as needed. It is important to note that 0.8 g/kg is adequate for most physically active people. The higher intake guidelines are reserved for intense levels of performance.[7] Protein intake above the recommendations can lead to increased body fat if caloric needs are exceeded. The body can convert excess dietary protein to body fat.

The example below uses 1.3 g/kg to estimate protein needs for an endurance athlete. On a typical training day, a protein intake of 1.3g/kg is a good starting point for an endurance athlete. On high intensity training days, or days that focus on resistance exercises, a protein intake from 1.5- 2.0g/kg may be more appropriate to accommodate an increase in muscle tissue stress. The higher protein recommendations for athletes fall within the AMDR guidelines for protein (10-35% of total daily calories). These increased protein needs can be met by eating common, high quality protein foods. Protein supplements and protein fortified foods are not necessary to meet these increased protein needs.

Photo by Bluewater Sweden on Unsplash

Estimating Protein Needs (Endurance Athlete)

Example: Convert the runner's weight to kilograms as before

140 pounds = 63.6 kg then multiply that number by 1.3 g/kg

2.2 pounds/kg

Estimating Protein Needs
(Endurance Athlete)

Example: Convert the Runner's Weight to Kilograms as Before

140 pounds = 63.6 kg
2.2 pounds/kg

Then Multiply That Number By 1.3 g/kg

63.6kg x 1.3g/kg = **83 g of protein per day**



63.6 kg x 1.3 g/kg = **83 g of protein per day**

Protein intake beyond these recommendations has not been shown to further enhance muscle gains for competitive athletes under normal circumstances. The timing of protein intake is another consideration that may impact muscle recovery and gains. For example, 20 grams of high-quality protein is recommended within 2 hours after exercise to optimize muscle growth and recovery.[10]

Key Takeaways

- *The standard protein recommendation for a healthy adult is 0.8 grams per kilogram of body weight per day, which is the amount needed to maintain protein balance.*
- *A person is in positive protein balance when they consume more protein than they lose, which is necessary during periods of growth pregnancy, and athletic training.*
- *Athletes and those engaged in regular, rigorous physical activity have higher protein needs, with recommended intakes ranging from 1.2 to 2.0 grams per kilogram of body weight per day.*
- *Protein intake for athletes can be met through common, high-quality protein foods, and supplements are not necessary.*
- *For optimal muscle recovery and growth, it is recommended to consume about 20 grams of high-quality protein within two hours after exercise.*

References (see below)

- 10. Academy of Nutrition and Dietetics. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: Nutrition and Athletic Performance. J. Acad Nutr Diet. 2016; 116(3): 501-528.

9.9

Protein Quality

6.9 Protein Quality

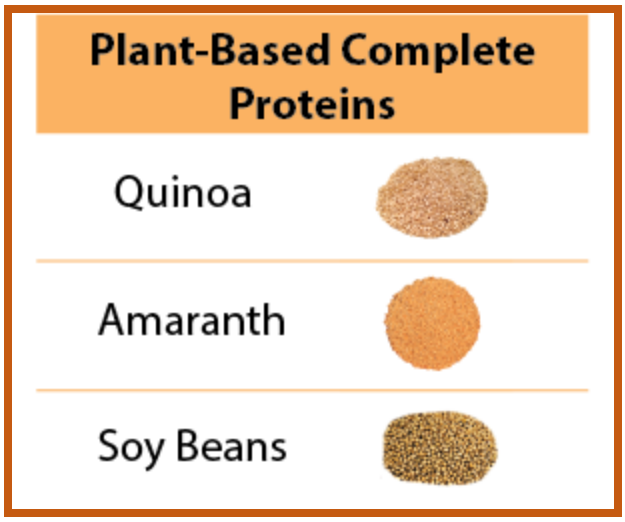


Table 1: Examples of plant-based complete proteins. Soy Bean Photo by Tris T7 under CC BY 3.0 license With . Quinoa Photo provided from PickPik with edits to the photo. Amaranth Photo by Niedereschbach under CC BY-SA 3.0 license with edits.

While protein is contained in a wide variety of foods, it differs in quality. High-quality protein contains all the essential amino acids in the proportions needed by the human body. Foods that provide low amounts of one or more of the essential amino acids are called **incomplete proteins**, those that contain all the essential amino acids in good proportions are called **complete proteins**. The digestibility of the protein also needs to be considered when judging the quality of protein. Generally complete proteins are also digested well.

High-quality protein is typically found in animal products like meat, fish, poultry, milk, eggs and cheese. Plant protein is typically lower in quality. For example, legumes, nuts and seeds are high in protein, but the quality of the protein is low (incomplete protein). There are a few exceptions to this general pattern. For example, gelatin is an animal derived protein, but

it is very low quality. On the other side the protein in quinoa, amaranth, and soy are plant based proteins that are very high quality (complete protein).

Protein complementation

The discussion up to this point could lead some to believe that animal protein consumption, or regular consumption of one of the few high-quality plant protein sources would be necessary to maintain proper growth and development, but this is not true. If combinations of lower quality protein sources are included in a person's diet on a regular basis, they typically will **complement** each other to form a complete protein. For instance, many grains are typically lacking in the amino acid lysine and possibly threonine (called the **limiting amino acids**), but adequate in the other essential amino acids; whereas legumes are low in methionine but adequate in lysine and threonine. If eaten together they compensate for the weakness of the other. This is called **protein complementation**. For example, a wheat tortilla with black beans is a good example of the principle in action. Complementary protein sources do not have to be consumed at the same time—as long as they are consumed within the same day in adequate amounts, protein needs will be met.

Foods	Limiting Amino Acid	Complementary Food	Application
Legumes	Methionine	Grains, nuts, seeds	Hummus and flat bread
Grains	Lysine, Threonine	Legumes	Wheat tortilla with black beans
Nuts and Seeds	Lysine	Legumes	Salad with kidney beans and assorted nuts and seeds

Table 2: Complementation of proteins

Key Takeaways

- *Protein quality is determined by the food's ability to provide all essential amino acids in the proportions needed by the body.*
- *Complete proteins, which contain all essential amino acids, are typically found in animal products, while most plant proteins are incomplete.*
- *Exceptions to this pattern exist, as some plant foods like soy, quinoa, and amaranth are complete proteins, while some animal products like gelatin are incomplete.*
- *It is possible to obtain all essential amino acids by combining different incomplete protein sources, a process known as protein complementation.*
- *For protein complementation to be effective, the complementary foods do not have to be consumed at the same meal, but rather within the same day.*

References (see below)

9.10

Protein Choices

6.10 Protein Choices

In general, animal proteins such as meat appear to have some clear advantages over plant proteins when considering the quality of the protein. Animal protein is more digestible than plant proteins and typically contain all of the essential amino acids. This can be particularly important if dietary protein resources are scarce. Unfortunately, when dietary protein is scarce, animal protein sources may be harder to come by because they are more expensive to produce. It takes high amounts of animal feed (generally plant products) to produce a small amount of meat protein (See highlight on “efficiency” of animal protein production). In addition, as a country’s income increases, the demand for meat protein sources also increases since it tends to be preferred. With global economies growing, it is expected that the demand for meat protein may double in the next 30 years.[11]

There are other important factors to consider when selecting dietary protein sources. Observational research supports a correlation between meat intake, especially red meat and processed meats, and the incidence of many chronic diseases, such as cancer, cardiovascular disease, and diabetes.[12]

The exact reason for this correlation is unclear due to several confounding factors. For instance, as protein intake from red meat and processed meat goes up, often saturated fat, cholesterol, and caloric intake also increases. It is difficult to determine which factor (the red meat, saturated fat, cholesterol or increased calories) is responsible for the increased rate of these chronic diseases. Over the last few years, the general public has become more aware of the health concerns associated with high consumption of red meat and processed meats as well as the environmental impact of meat production. The increased awareness of these issues may slow the expected increase in meat protein consumption over time. This makes it hard to predict the expected increase in the demand for meat protein sources over the next 30 years.

The health benefits of increasing whole grains and vegetable intake were outlined in the Dietary Guidelines for Americans (see chapter 3). Whole grains can be an excellent contributor to our overall protein intake. Grains with high quality protein such as soy, quinoa, and amaranth are good nutrient-dense options to consider, especially when sources of animal protein are scarce or not included in the diet. Grains with lower quality protein can be complemented with other lower quality plant protein sources such as legumes (black beans, lima beans, chickpeas, lentils, peanuts etc.) to make complete protein. Nuts and seeds are another excellent source of lower quality plant protein.



Variety of healthy whole grains in a market in Africa. Photo by v2osk on Unsplash.

The current guidelines allow for a wide range of protein intakes, anywhere from 10-35% of daily calories. Protein is not recommended as the primary macronutrient in our diet but may make up to a third or slightly more of our calories.



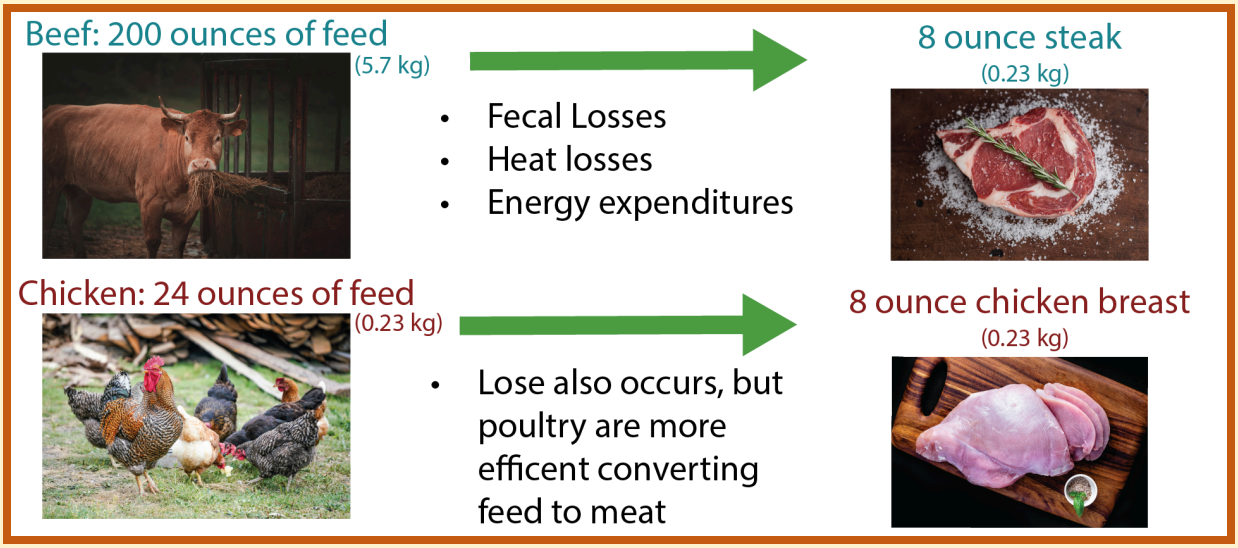
Figure 14: Examples of legumes. Black Eyed Pea Image by Sanjay ach at the English-language Wikipedia under license with edits. "Cranberry Beans Image by Jen on Flickr under CC BY-NC-SA 2.0 license with edits. Yellow Lentils Photo from Pxhere under CC0 1.0 with edits by underlicense with edits.

In the Word of Wisdom, we are counseled to eat meat sparingly. It is important to recognize the terms protein and meat cannot be used interchangeably. By using a rich source of plant proteins, a person's diet can be higher in protein, but meat can still be used sparingly. Having a balanced diet rich in plant proteins containing whole grains, beans and peas, and nuts and seeds is consistent both with the doctrine found in the Word of Wisdom and with current scientific evidence that encourages a more plant-based food eating pattern. A biblical example of plant based sources of protein is pulse, edible seeds of plants in the legume family, eaten by Daniel, Shadrach, Meshach and Abednego.

It appears that globally it is important to have available a variety of protein sources, both animal and plant to optimize nutrition, protect the environment and to utilize resources efficiently. Ongoing research will help us to clarify the correct balance.

Highlight: Efficiency of Animal Protein Production

In the next 30 years not only do they expect the demand for meat to continue to increase, but type of meat being consumed is expected to continue to change as well. For example, poultry is being chosen at an increasing rate over red meats like beef. This is likely in part due to the recognized health benefits of choosing meat such as poultry or fish over red meats such as beef. Efficiency is also a factor. It takes roughly 200 ounces of feed (hay and silage) for a cow to produce one 8-ounce steak. It only takes 24 ounces of feed (corn and grains) for a chicken to produce an 8-ounce breast. [1,2] The chicken is much more efficient in translating their food to meat. Fish are even more efficient than chicken. We then eat the steak or chicken and then convert a fraction of that for our use (which represent another loss of the original food energy). When you consider that the farmer that raised the feed for the animals had to use land that could have been used for other crops, possibly gas to run equipment, water resources etc… selecting animals that are efficient makes sense, particularly if resources are scarce. The discussion of this topic is much more complicated and very interesting. For example, when cows are grazed on open range (land typically not used for growing crops), or are fed left over French fries from fast food restaurants (yes, this does happen), even though they are inefficient in converting that feed to meat, it still can be considered an efficient way to use the resources available. When considering the best way to feed people, eating a diet centered on plant food is the most efficient. This completely skips the losses that happen when the animals convert the plant materials to body tissues. These principles support the benefits of a plant centered diet balanced with modest meat consumption that is demonstrated in the DASH and Mediterranean eating styles and the Word of Wisdom.



Cow Image by Juan Manuel Sanchez on Unsplash . Steak Image by Edson Saldaña on Unsplash . Chickens Image by Zosia Szopka on Unsplash . Raw Chicken Image by Eiliv Aceron on Unsplash .

1. Alexandar et al. (2016) Human appropriation of land for food: The role of diet. Global Environmental Change. 41:88-98

2. Ritchie, H. and Roser, M. (2019). Meat and Dairy Production. Published online at “Our World in Data.” Retrieved from https://ourworldindata.org/meat-production

3. Images: Manfred Antranias Zimmer (cow), Tomwieden (steak), Andreas Göllner (chicken), Siwon Lee (breast) courtesy of Pixabay

Key Takeaways

- *While animal proteins are generally more digestible and complete, their production is less efficient and more expensive compared to plant proteins.*
- *There is a recognized correlation between the consumption of red and processed meats and an increased risk of chronic diseases, though the exact cause is not fully understood.*
- *A plant-based diet is the most efficient way to produce food, as it avoids the energy losses that occur when animals convert plant material into body tissues.*
- *A person can have a high protein diet while still consuming meat sparingly by incorporating a variety of plant-based protein sources such as legumes, whole grains, nuts, and seeds.*
- *The text suggests that choosing more efficient animal protein sources like poultry and fish as beneficial for both health and environmental reasons.*

References (see below)

- 11. Food and Agricultural Organization of the United Nations (June 3rd, 2021). Livestock production http://www.fao.org/3/y4252e/y4252e07.htm
- 12. Harvard School of Public Health. The Nutrition Source: What should I eat: Protein (June 3rd,2021) https://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/protein/

10

Chapter 10: Lipids



Natural sources of lipids includes plant and animal sources.

10.1

Introduction to Lipids

7.1 Introduction to Lipids

The study of **lipids** is a dynamic and often debated area of nutrition. Most people know that lipid intake is linked to health outcomes like cardiovascular disease, weight management, and other chronic conditions. While the amount and type of fats we eat do impact these health areas, the many important roles of lipids in the body are often underappreciated.

Dietary fat is essential for preventing deficiency-related diseases and supporting many bodily functions. Interestingly, some populations have thrived on high-fat diets. For example, the Inuit consume large amounts of fish fats, and people in Mediterranean regions regularly use olive oil.

Lipids provide nine Calories per gram, which is more than twice the amount from protein or carbohydrates. Because of this, they are often linked to weight gain, but the body's ability to store fat has historically been crucial for survival.

Lipids are made mainly of carbon, hydrogen, and oxygen and serve three main functions:

- They are **structural components** of cell membranes.
- They act as **energy stores**.
- They function as **signaling molecules** important for various processes.

In foods, fats also enhance flavor and texture. For example, the flaky crust of a pie depends on fat.

Key Takeaways

- *While often associated with health problems, lipids are essential for precenting deficiency diseases and supporting many bodily functions.*
- *Lipids are the most energy-dense macronutrient, providing 9 Calories per gram, more than doable the energy from protein or carbohydrates.*

- *The three main functions of lipids in the body are serving as structural components of cell membranes, acting as energy stores, and functioning as signaling molecules.*
- *In foods, fats are important for enhancing flavor and texture.*

References (see below)

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10.2

Categories of Lipids

7.2 Categories of Lipids

Lipids are a family of organic compounds that are mostly insoluble in water. Lipids are typically broken into three classes: the glycerides, sterols, and phospholipids.

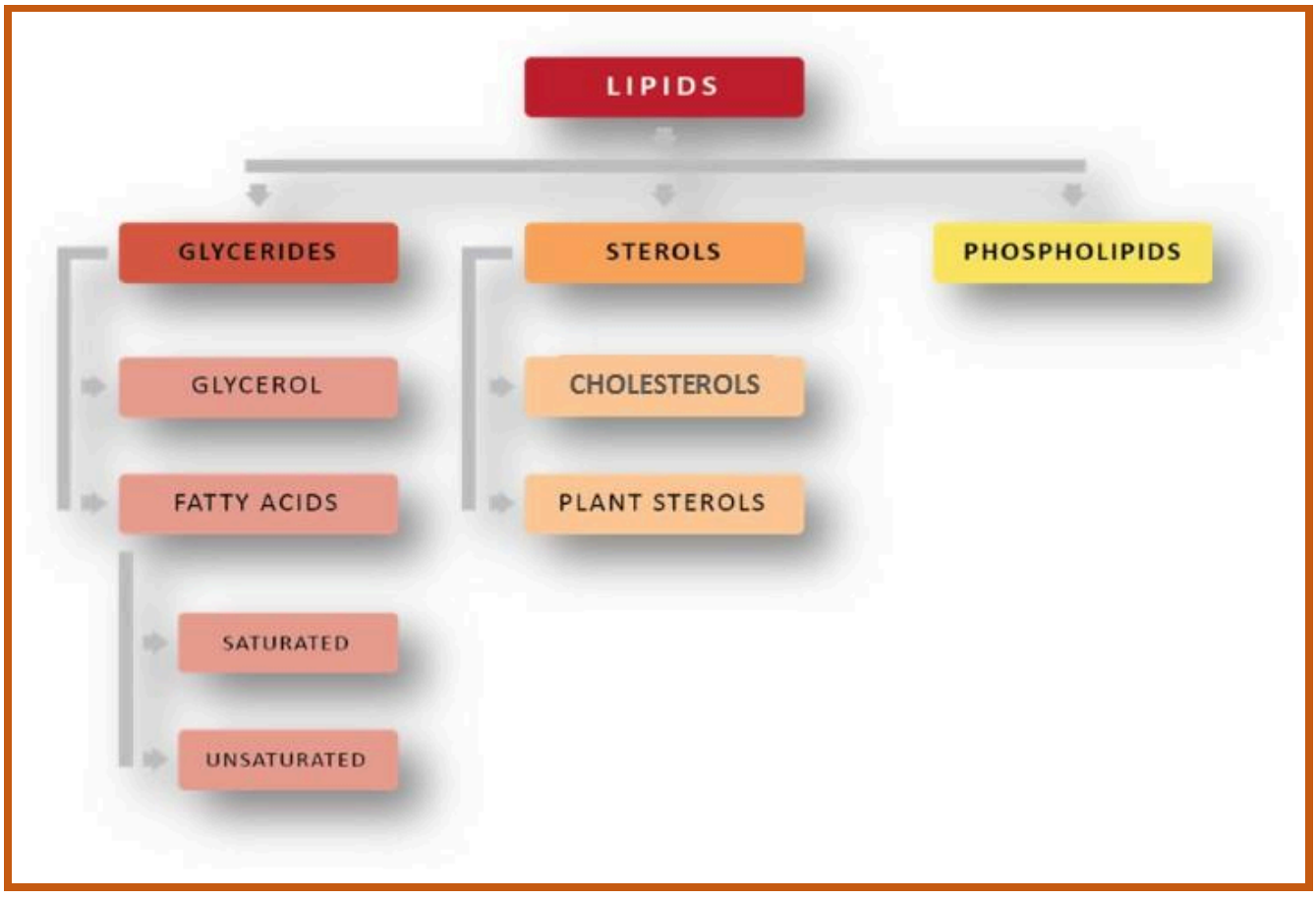


Figure 7.1: Categories of lipids include glycerides, sterols, and phospholipids

The Glycerides

Practically, the terms fats, oils, and glycerides are discretionary and can be used interchangeably. In this chapter when we use the word fat when we are referring to any glyceride. Fats make up more than 95 percent of lipids in the diet and are commonly found in a wide variety of foods. Fried and processed foods, butter, whole milk, cheese, cream cheese, and some meats are examples of foods that contain fat that when isolated is solid at room temperature (see Table 1). Avocados, olives, corn, vegetable oils, seeds, and nuts are foods that contain fat that when isolated are liquid at room temperature (technically oils). The glycerides can be subdivided into the **fats**, which are solid at room temperature and the **oils** that are liquid at room temperature.

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Lipid Types		Common Foods
Soild Fats (Saturated Fats)		Fried and processed foods, butter, whole milk, cheese, cream cheese, cream cheese, and some meats are examples
Liquid Fats (Saturated Fats)		Avocados, olives, corn, vegetable oils, seeds, and nuts

Table 1: Sources of lipids. Created by AP.

The main structural components of all the **glycerides** include carbon, oxygen and hydrogen. The lines in the figure below (Figure 7.2) represent the number of bonds that are possible on each element. Carbon can be bound to four other elements, oxygen can be bound to two and hydrogen to one other element. These patterns of bonding will be apparent as we start to look at the structure of the glycerides.

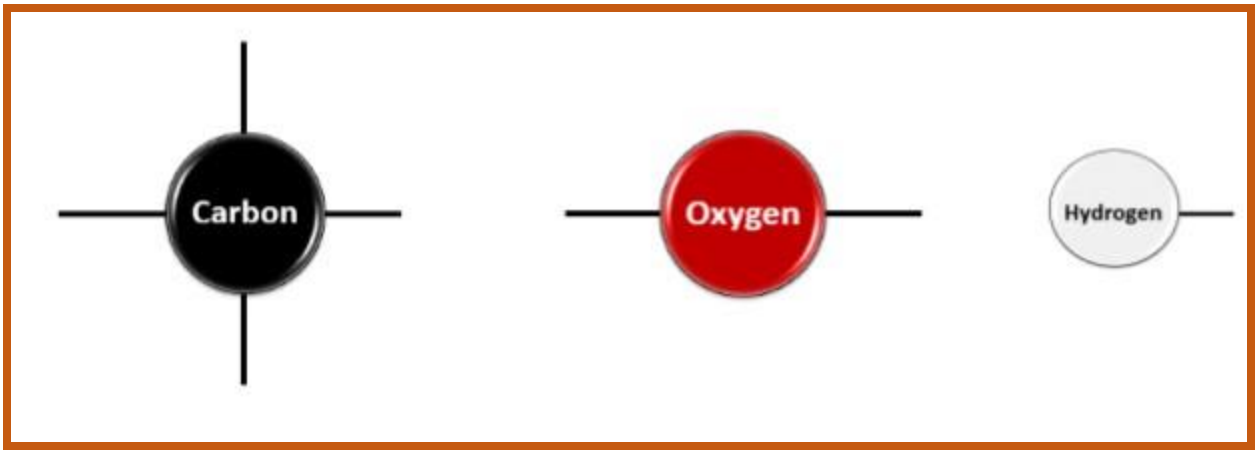


Figure 7.2: Elements found in glycerides

Triglycerides are the main form of fat found in the body and in the diet. Fatty acids and glycerol are the building blocks of triglycerides. To form a triglyceride, a glycerol molecule is joined to three fatty acid chains (see Figure 7.3). Triglycerides contain varying mixtures of fatty acids. Glycerides can also exist as diglycerides and monoglycerides (see Figure 7.4). Glycerol is a small molecule made up of only 3 carbons. Fatty acids are larger structures varying in length from 4 to 24 carbons long. Glycerol and fatty also contain oxygen and hydrogen. Fatty acids have an acid group located at one end of the carbon chain.

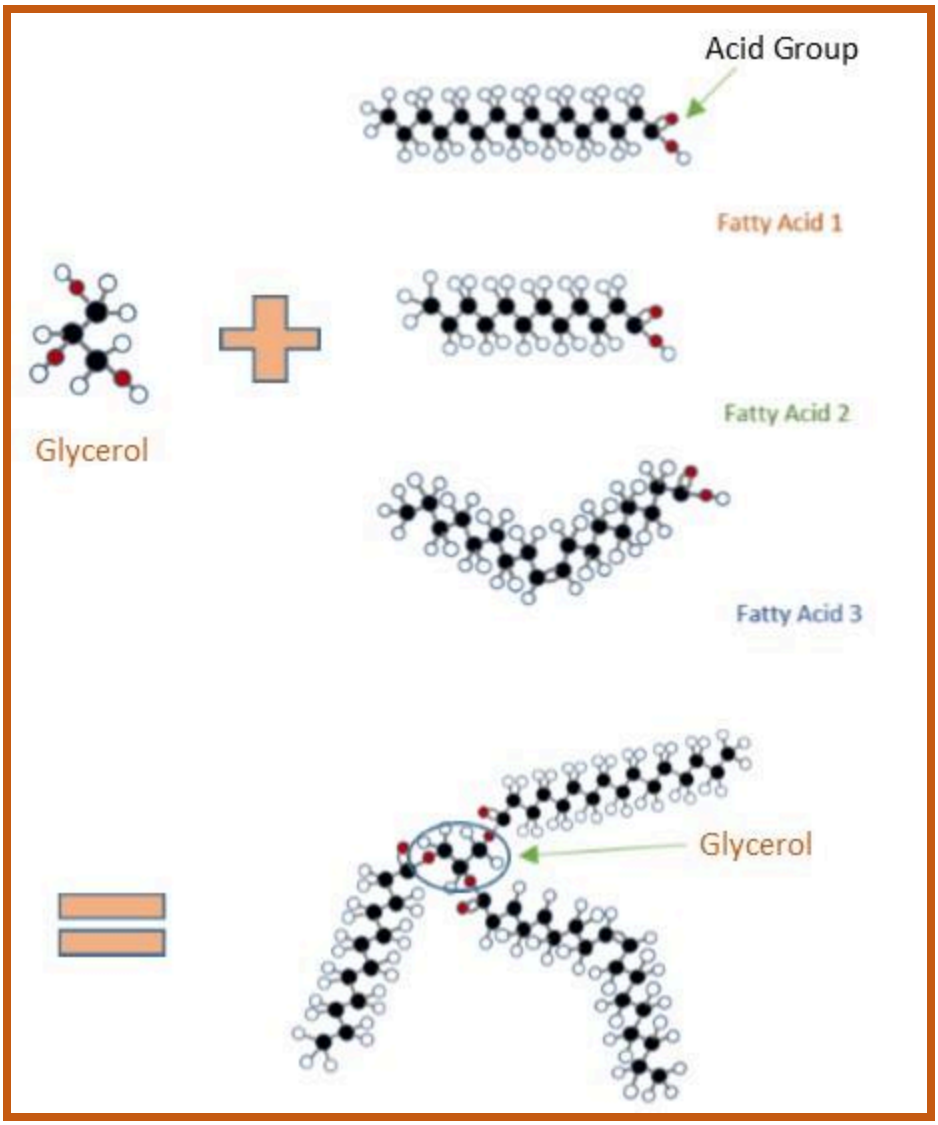


Figure 7.3: Formation of a triglyceride from a glycerol and three fatty acids

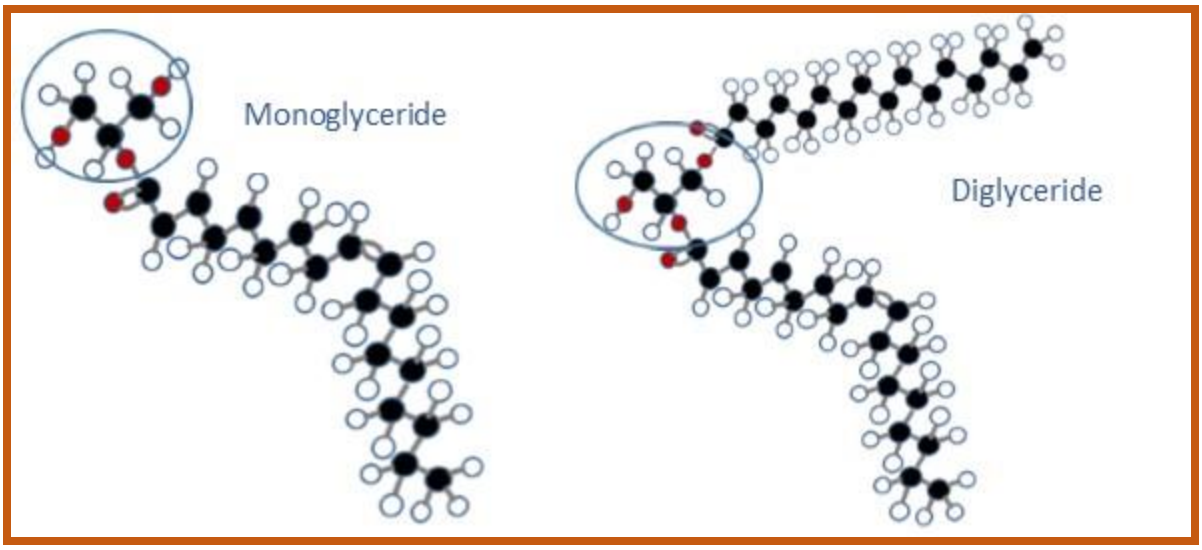


Figure 7.4: Mono and di-glycerides

Phospholipids

Structurally **phospholipids** are similar to triglycerides, yet they have a uniquely different function. Like triglycerides, phospholipids have a glycerol backbone. But unlike triglycerides, phospholipids only have two fatty acid molecules attached to the glycerol backbone. In place of the third fatty acid chain, phospholipids have a phosphate group. This unique structure makes one end of phospholipids water-soluble and the other end fat-soluble.

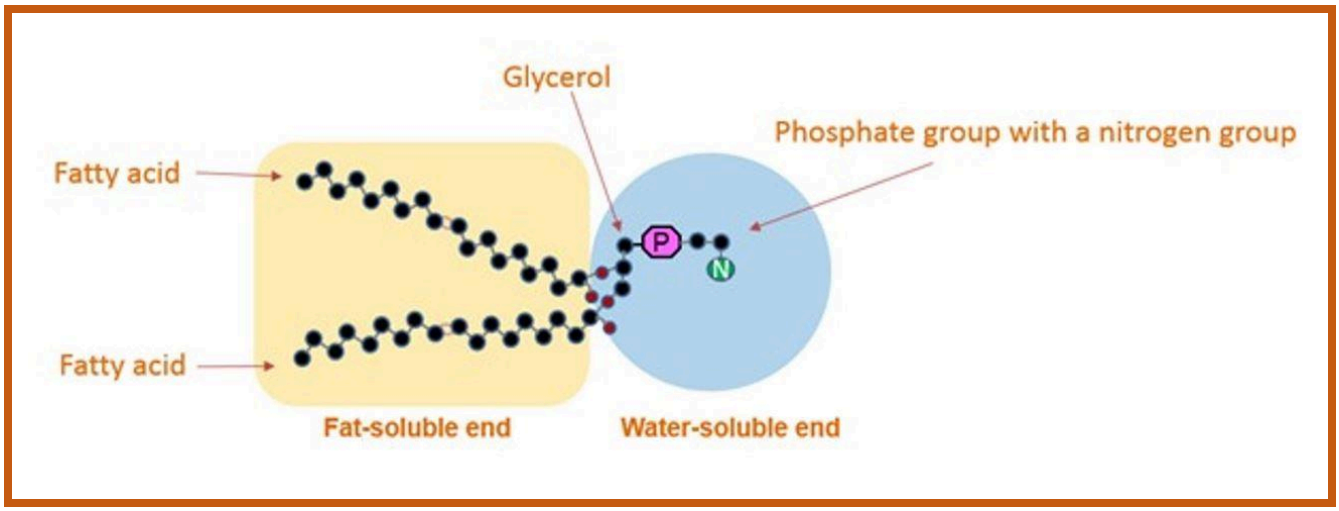


Figure 7.5: Structure of a phospholipid showing the fat-soluble and the water-soluble ends

Phospholipids are referred to as **amphiphilic**—the fatty-acid sides are **hydrophobic** (dislikes or repels water), and the phosphate group is **hydrophilic** (likes or attracts water).

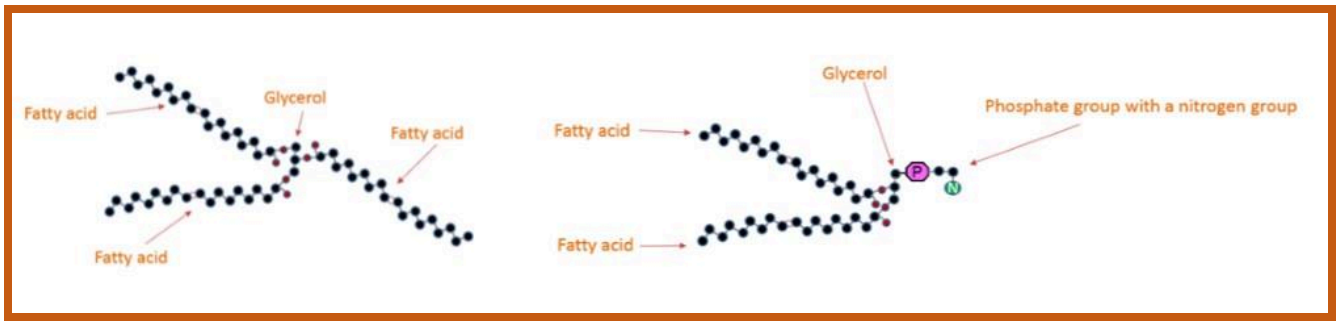


Figure 7.6: Structure of a triglyceride compared to a phospholipid

The unique structure of a phospholipid allows it to interface between water- and fat-soluble substances. The presence of phospholipids in foods or the body allows fat-soluble and water soluble substances to exist together comfortably. This is called emulsification, and phospholipids can be referred to as **emulsifiers**. For example, mayonnaise is made of water-soluble (vinegar) and fat-soluble substances (oil). It also contains egg yolk which is a source of phospholipid. When mixed together just right the oil and vinegar associate well together in the presence of the phospholipids. Phospholipids are common in sauces and creams.

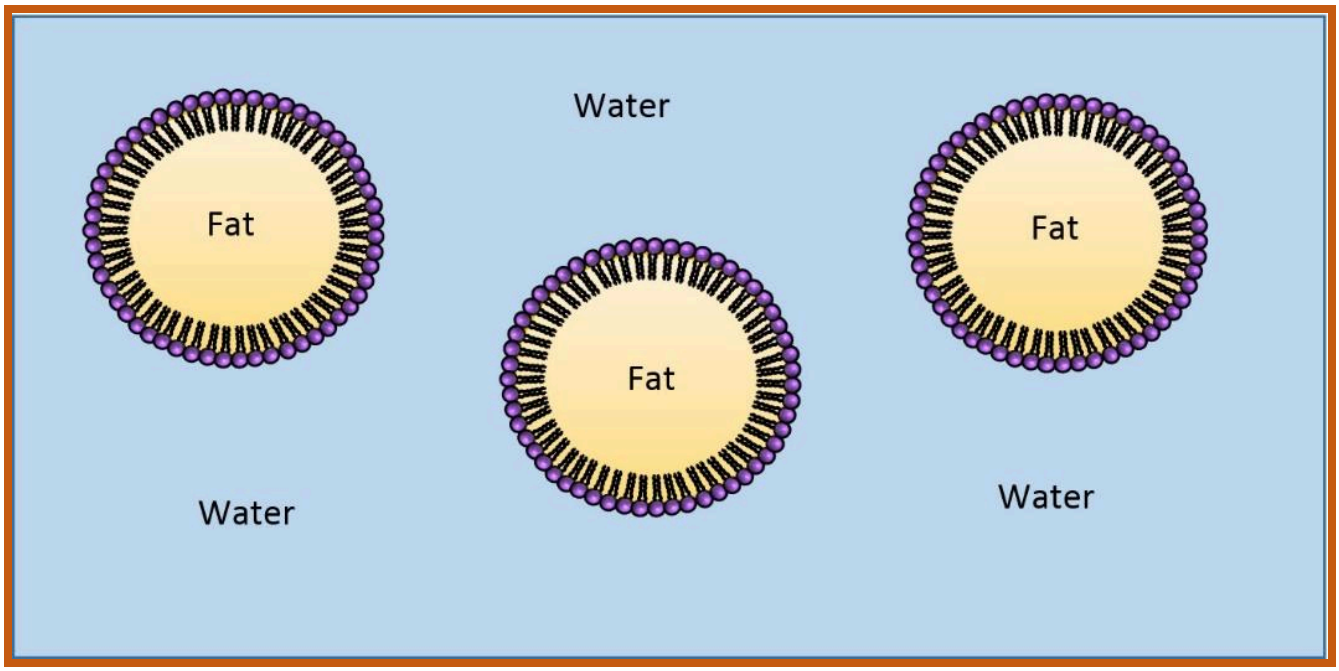


Figure 7.7: Lipid droplets surrounded by phospholipids are suspended in water.

In the body, phospholipids have a variety of roles. They bind together to form cell membranes. The amphiphilic nature of phospholipids governs their function as components of cell membranes. The phospholipids form a double layer in cell membranes, thus effectively protecting the inside of the cell from the outside environment. They also assist in the transport of fat and cholesterol in the blood stream.

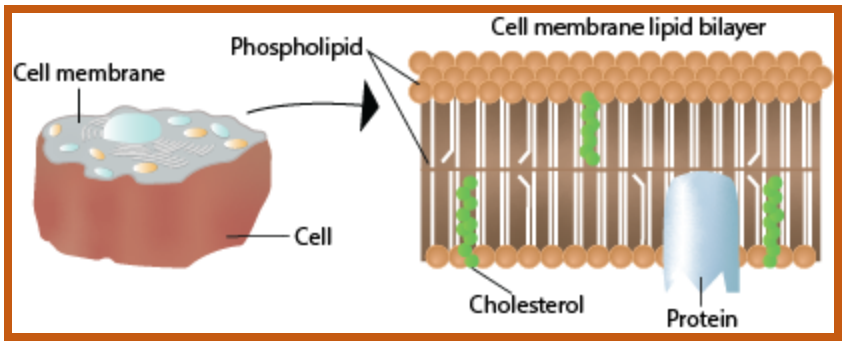


Figure 7.8: Role of phospholipids in cellular membranes. Created by AP.

Sterols

Sterols have a very different structure from triglycerides and phospholipids. 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.

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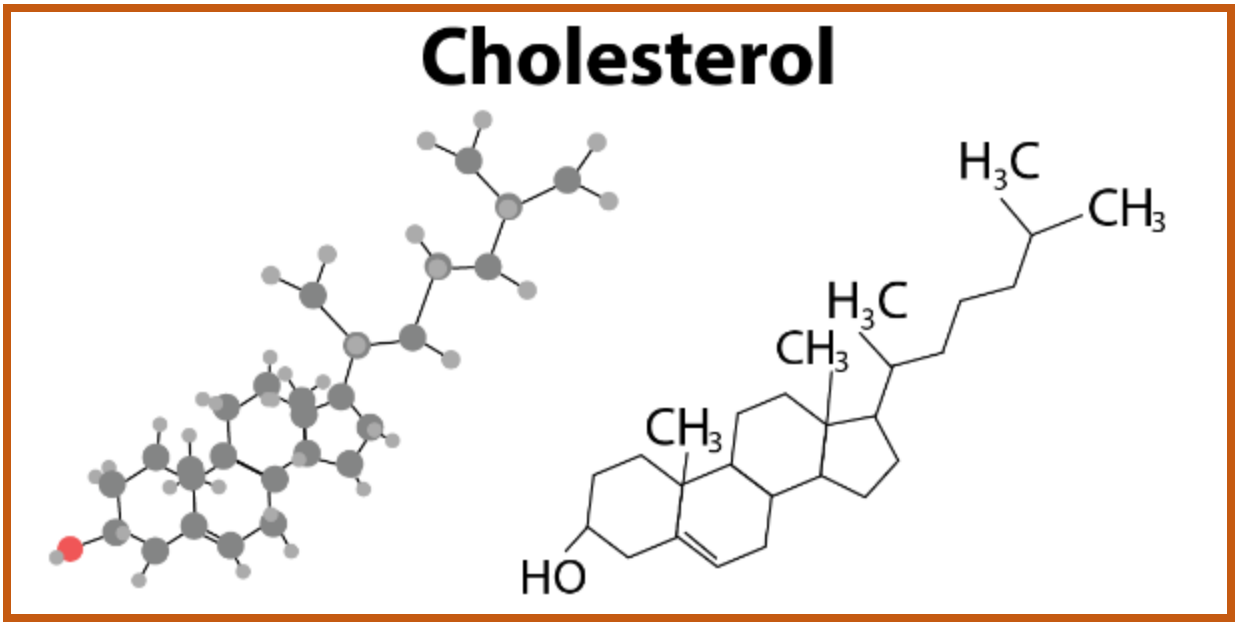


Figure 7.9: Structure of cholesterol

Because cholesterol is part of the plaque that can narrow arteries potentially leading to heart attacks and strokes, it has developed a negative image. Cholesterol has specific beneficial functions to perform in the body. Like phospholipids, cholesterol is present in all body cells, and has a key role in cell membrane structure and function (see Figure 7.10). Approximately 25 percent of the cholesterol in the body is localized in brain tissue. In the brain it has an important role a component of cell membranes as well as many other key physiological roles.

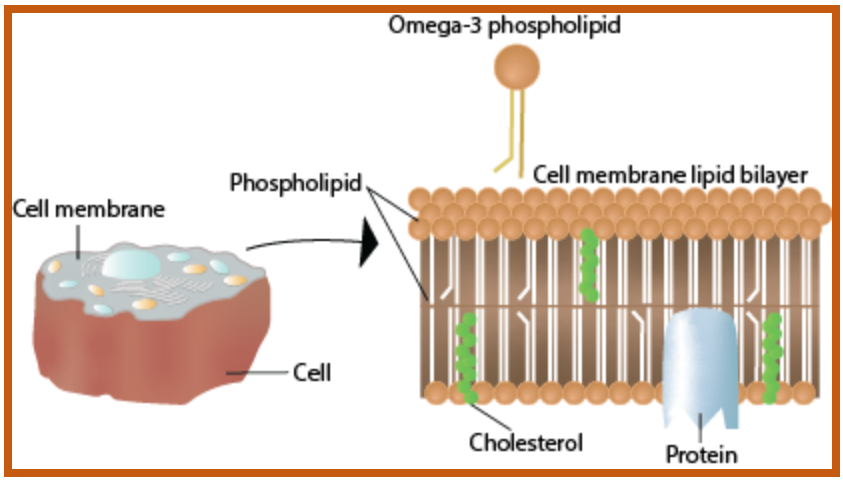


Figure 7.10: Cholesterol's place in the cellular membrane. Created by AP.

Cholesterol is also used in the body to make a number of important compounds, including vitamin D, sex hormones (progesterone, testosterone, estrogens), and bile for digestion of fats. Cholesterol is not metabolized and therefore is not an energy source for the body.

Although cholesterol is preceded by its infamous reputation, it is clearly a vital substance in the body that possess a concern only when there is excess accumulation. Cholesterol is not essential in the diet because it can be synthesized by the liver. Many foods contain cholesterol. Typically, when we eat more cholesterol, the body will reduce production of cholesterol to maintain a balance in the body. Foods that are rich in dietary cholesterol include liver, eggs, red meats, and shellfish. Almost any animal product will contain some cholesterol. Plant products do not contain cholesterol, but some plants do contain other types of sterols (and stanols) that do resemble cholesterol in structure. Some of these **plant sterols** can inhibit cholesterol absorption in the human body, which can contribute to lower cholesterol levels.[3] These plant sterols are found naturally in foods such as nuts, vegetable oils, seeds, cereals, and beans. They can also be found in other food though fortification or they can be purchased in a supplement form.4

Key Takeaways

- *Lipids are broken down into three main categories: glycerides (fats and oils), phospholipids, and sterols.*
- *Triglycerides, the most common form of fat in the diet, are composed of a glycerol molecule attached to three fatty acid chains.*
- *Phospholipids have a unique structure with both water-soluble and fat-soluble ends, allowing them to act as emulsifiers and form cell membranes.*
- *Cholesterol is a type of sterol that, despite its negative reputation, is a vital component of all body cells and is used to create hormones and vitamin D.*
- *The body can synthesize its own cholesterol, so it is not an essential nutrient in the diet.*

References (see below)

- 3.Shaghaghi MA, Abumweis SS Jones PJH. Cholesterol-lowering efficacy of plant sterols/stanols provided in capsule and tablet formats: Results of a systematic review and meta-analysis. J Acad Nutr Diet. 2013; 113: 1494-1503.
- 4. Jong AD, Plat J, Mensink RP. Metabolic effects of plant sterols and stanols. J Nutr Biochem. 2003:362-369.

10.3

Types of Fatty Acids

7.3 Types of Fatty Acids

Chain Length

Fatty acids can come in different lengths of carbon chains: short-chain (4-7 carbons), medium chain (8-12 carbons) and long-chain (more than 12 carbons).[1] The length of the carbon chain of the fatty acids affects its melting point. The shorter the chain length the lower the melting point. (see Figure 7.11)

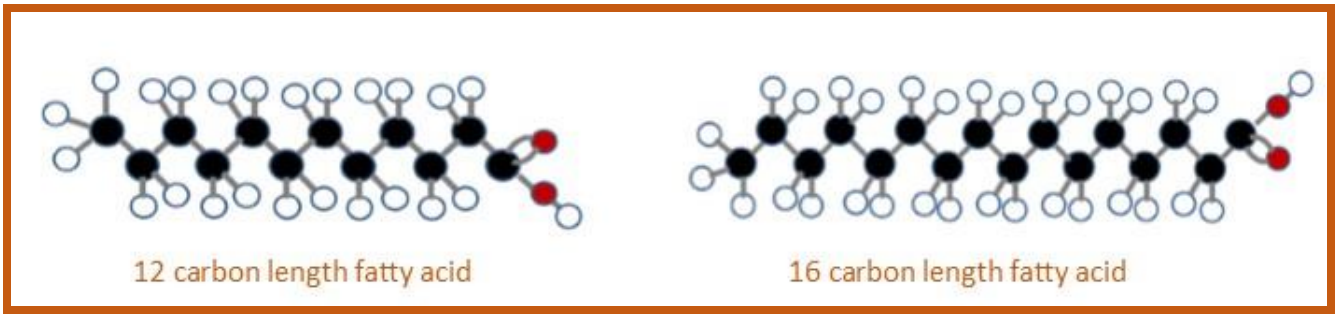


Figure 7.11: Fatty acids of varying chain lengths

Saturation

Fatty acids can vary in length but also in the number of double bonds. Fatty acid chains are held together by carbon atoms that attach to each other and to hydrogen atoms. The term saturation refers to whether or not a fatty acid chain is filled (or "saturated") to capacity with hydrogen atoms. If each available carbon bond holds a hydrogen atom, we call this a **saturated fatty acid chain**. All carbon atoms in a saturated fatty acid chain are bonded with single bonds.

Sometimes the chain has a place where hydrogen atoms are missing. This is referred to as the point of unsaturation. When one or more bonds between carbon atoms are a double bond (C=C), that type of fatty acid is called an **unsaturated fatty acid**, as it has one or more points of unsaturation. Any fatty acid that has only one carbon to carbon double bond is a **monounsaturated fatty acid**, examples of oils high in monounsaturated fatty acids include olive, canola and avocado. A

polyunsaturated fatty acid is a fatty acid with two or more carbons to carbon double bonds or two or more points of unsaturation. Soybean oil contains high amounts of polyunsaturated fatty acids.

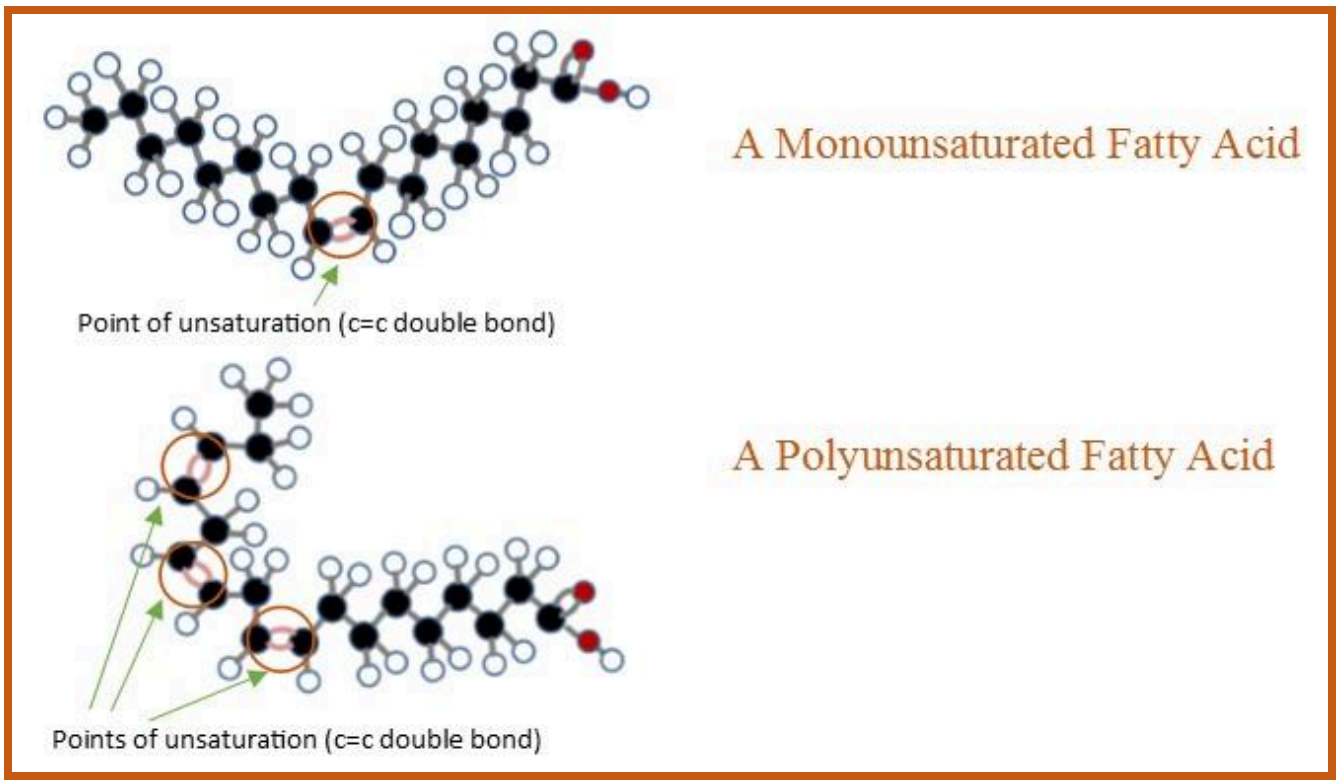


Figure 7.12: Mono and poly-unsaturated fatty acids.

Foods that have a high amount of saturated fat include whole milk, cheese, and many meat products. Fats from these foods will typically be solid at room temperature when separated out of the food. Butter is a good example of this principle in action. When milk fat is separated out of the milk and turned into butter, it remains solid at room temperature. The exception to this rule is the tropical oils (coconut and palm). They have a high percentage of saturated fatty acids but are considered oils. The short length of their fatty acid chains (they contain many fats only 8- 12 carbons long and are called medium chain fatty acids) cause them to melt at a lower temperature.

Foods rich in unsaturated fatty acids include olives, avocadoes, fish, nuts and seeds. When the oil is extracted from these foods it is liquid at room temperature. Knowing the connection between chain length, degree of saturation, and the state of the fatty acid (solid or liquid) can be helpful in making food choices. Generally having a diet rich in unsaturated fatty acids is better for a person's cardiovascular health than a diet rich in saturated fatty acids. [1] If the fat is visible, it can be a useful tool to judge what type of fat you are eating. If the fat in a food is not visible (for example in mixed foods like soups, cookies or ice cream), it is called a hidden fat. To know what kind of fat is in the food, refer to the recipe, ingredient list or nutrition facts label.

Partially and *Fully* Hydrogenated Oils

The amount and type of dietary fatty acids consumed play an important role in the prevention or development of cardiovascular disease. The introduction of a carbon double bond in an unsaturated fatty acid changes its shape depending on the position of the hydrogen atoms. When the hydrogen atoms are on the same side at the location of the double bond, it is called a cis bond, which bends the chain. Most naturally occurring unsaturated fats have this cis configuration (see Figure

7.13). When the hydrogen atoms are on opposite sides, it forms a trans bond, making the structure more linear (see Figure 7.14).

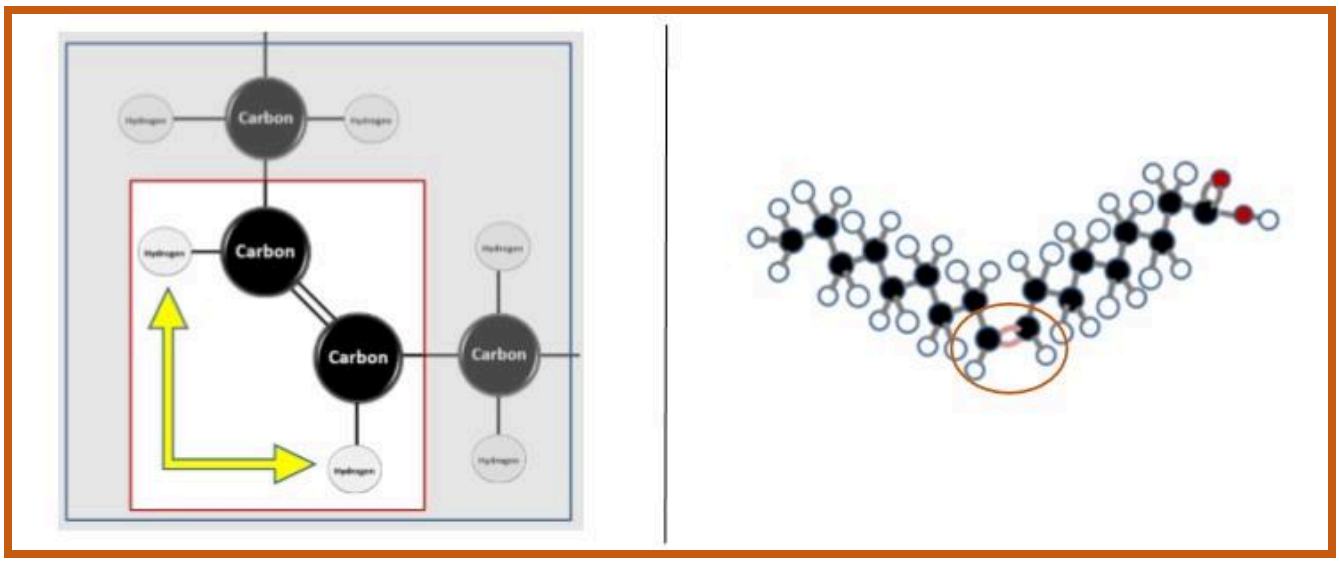


Figure 7.13: Example of a cis double bond

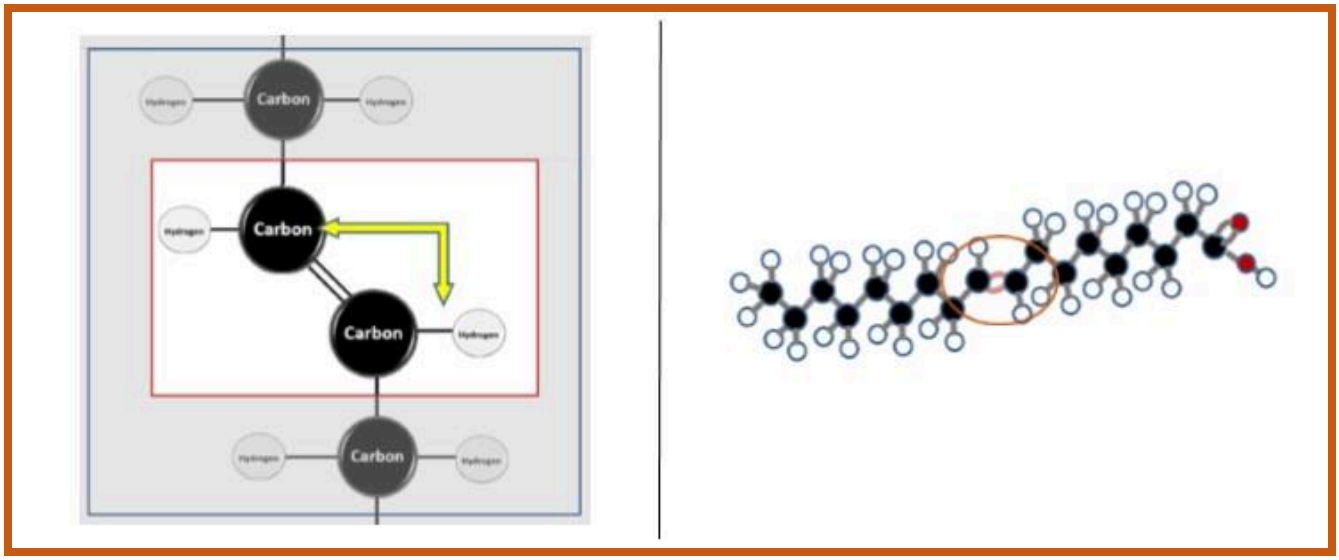


Figure 7.14: Example of a trans double bond

Most **trans fats** in food are not natural but are created through a process called **partial hydrogenation**, where hydrogen is added to unsaturated fatty acids. This process breaks some double bonds, converting some unsaturated fatty acids to saturated ones and changing some cis bonds to **trans bonds** (see Figure 7.15).

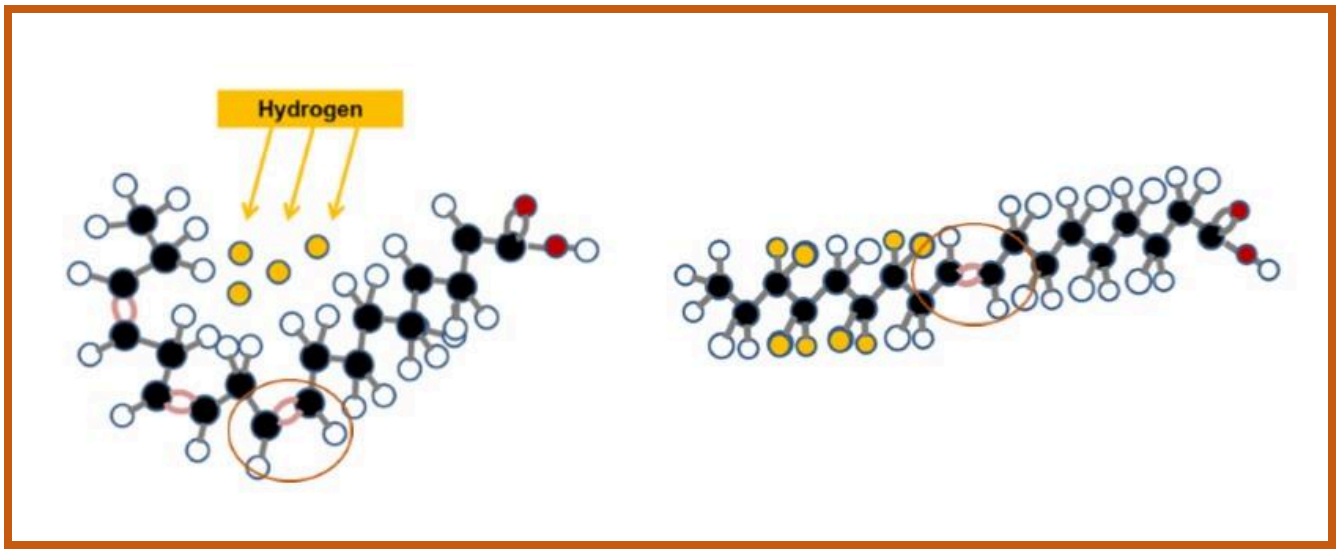


Figure 7.15: An example of a cis bond shifting to a trans bond during partial hydrogenation

Trans fats produced this way have a strong negative impact on lipoprotein levels. They increase LDL cholesterol and decrease HDL cholesterol, the worst possible scenario for cardiovascular disease risk. Although some naturally occurring trans fats are present in dairy and meat, these do not seem to be harmful in the same way.

In the United States, to improve heart health and reduce harmful fats in foods, the FDA determined in 2015 that partially hydrogenated oils are no longer "Generally Recognized as Safe" (GRAS) and set January 1, 2020, as the deadline for their removal from foods. To replace them, manufacturers now often use fully hydrogenated oils, which result in completely saturated fats, or naturally saturated fats like coconut and palm oils (see Figure 7.16).



Figure 7.16: Strategies used to eliminate trans fats in food products; the items in red replaced partially hydrogenated vegetable oils. Created by AP.

Fully hydrogenating *an oil converts all double bonds to single bonds, creating a completely saturated fat (see Figure 7.17).*

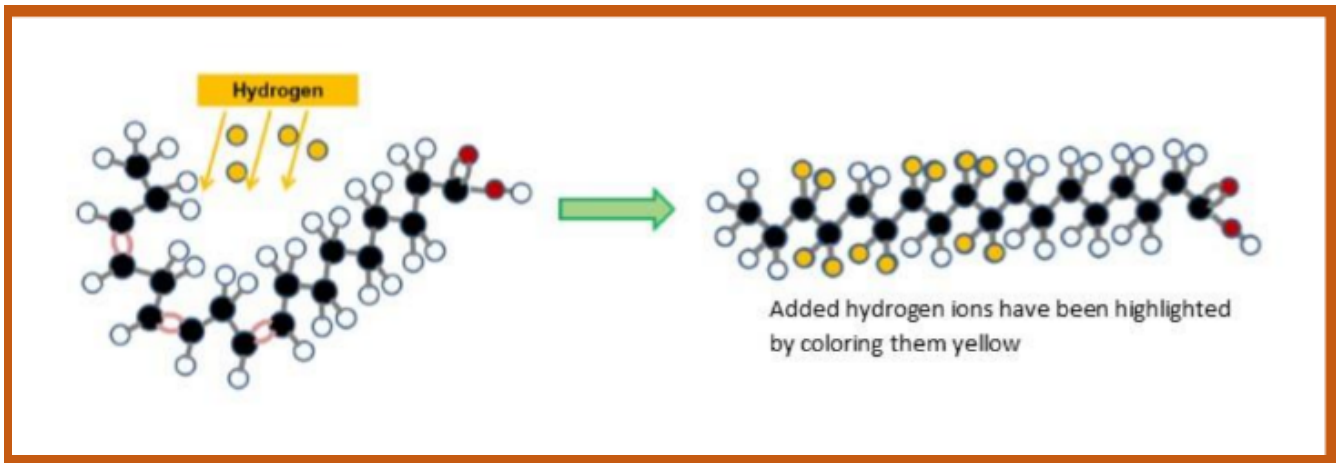


Figure 7.17: The process of fully hydrogenation (100%) removes all the double bonds in the fat, removing the possibility for the formation of trans fats, but leaving the fat completely saturated.Essential Fatty Acids

Essential Fatty Acids

Fatty acids are vital for the normal operation of all body systems. The fatty acids the body can make are called **non-essential fatty acids**. The fatty acids the body cannot make are called **essential fatty acids** and must be obtained from food. The two essential fatty acids are **alpha linolenic acid (ALA)** and **linoleic acid**. They are both 18 carbons long. The essential fatty acids are part of two larger families of fatty acids called the omega-3 and omega-6 fatty acids.

The omega 3 fatty acids have their first double bond three carbons from the omega end of the fatty acid (see Figure 7.18). The omega 6 fatty acids have their first double bond 6 carbons from the omega end.

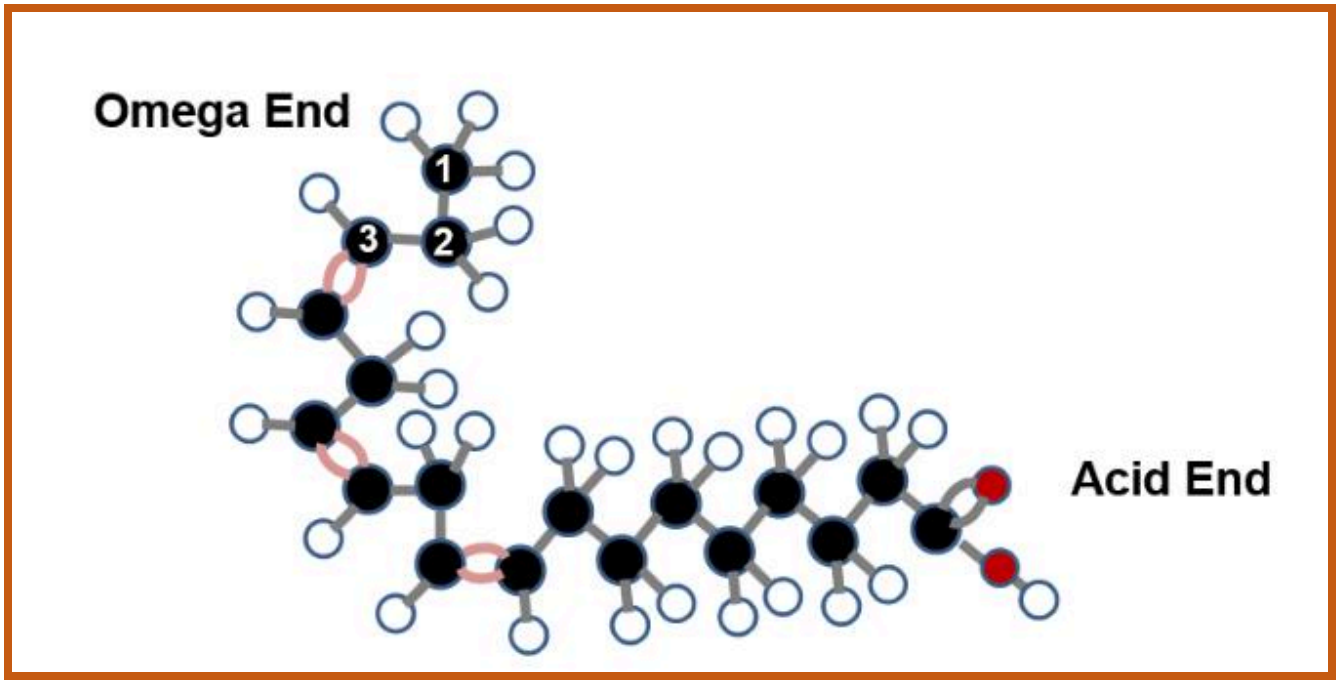


Figure 7.18: Example of an omega-3 fatty acid

The key fatty acids in the omega-3 family include alpha-linolenic acid (ALA), **Eicosapentaenoic Acid (EPA)**, and **Docosahexaenoic Acid (DHA)**. Although our body cannot make alpha-linolenic acid (ALA), it can make small amounts of

eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) from alpha-linoleic acid (ALA). Consequently, EPA and DHA are not considered essential. The key fatty acids in the omega-6 family are linoleic acid (LA) and arachidonic acid (AA). Similar to EPA and DHA, our body can make arachidonic acid (AA) from linoleic acid and is not considered essential (see Figure 7.19).

All the fatty acids in the omega-3 and omega-6 families have biologically significant functions and are important dietary components. Some of these fatty acids are precursors to important compounds called **eicosanoids**. Eicosanoids are powerful hormones that are involved in the regulation of many important body functions including clotting, inflammation, and blood pressure control.[5]

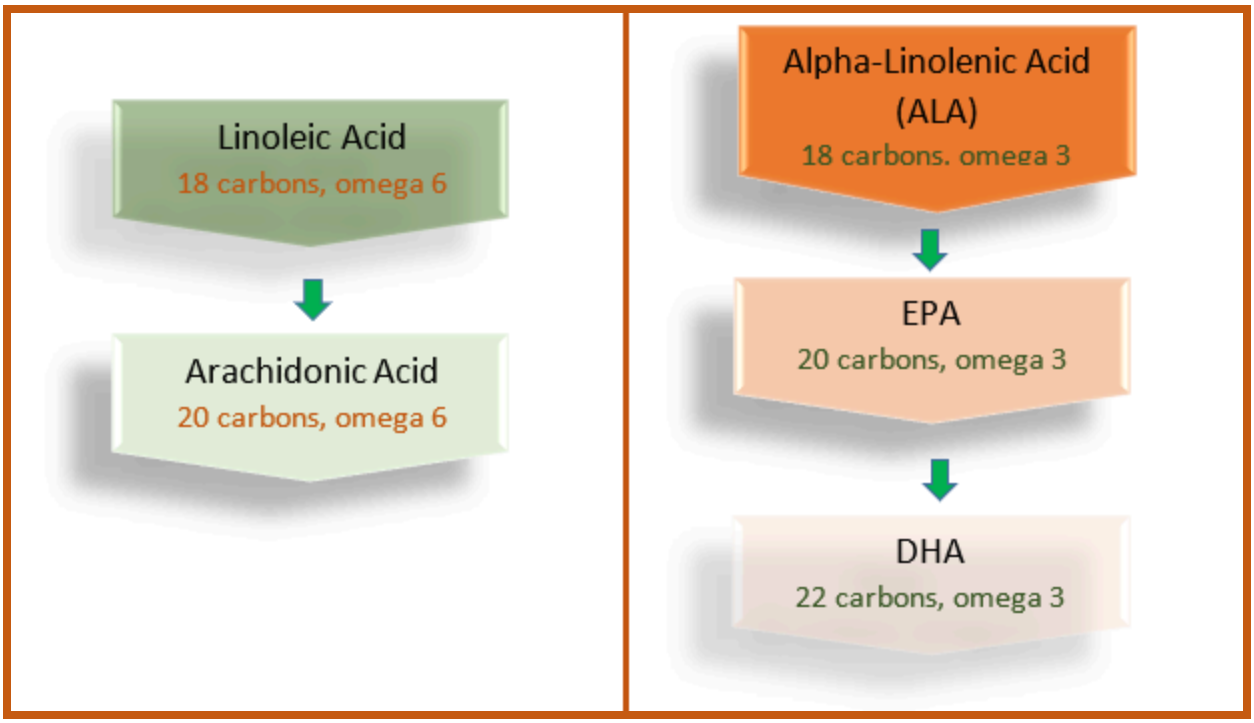


Figure 7.19: Omega-6 and Omega-3 fatty acids

Alpha-linolenic acid (an omega-3 fatty acid) and **linoleic acid** (an omega-6 fatty acid) are found in many plant-based oils and foods (see Figure 7.20). Because these essential fatty acids are widely available in our food supply, deficiencies are rare and usually only occur in cases of fat malabsorption disorders, such as cystic fibrosis. While both omega-3 and omega-6 fatty acids are important, most people consume enough omega-6 but often have low intake of omega-3 fatty acids. It is recommended to include more foods rich in omega-3 fatty acids.

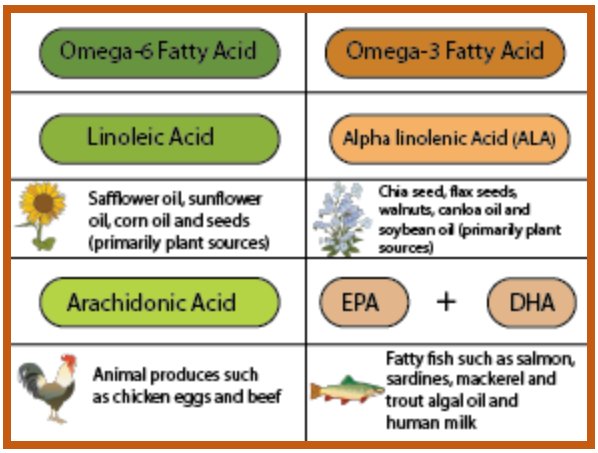


Figure 7.20: Dietary sources of omega-3 and omega-6 fatty acids. Sunflower Photo by magorrrka via pixabay. Flower Photo by dandelion_tea via pixabay. Chicken Photo by OpenClipart-Vectors via pixabay. Fish Photo by Clker-Free-Vector-Images via pixabay.

Key Takeaways

- *Fatty acids are classified by their chain length and the degree of saturation, which is determined by the number of double bonds.*
- *Saturated fats (with no double bonds) are typically solid at room temperature, while unsaturated fats (with one or more double bonds) are generally liquid.*
- *Trans fats, created through the process of partial hydrogenation, are particularly harmful to heart health by increasing LDL cholesterol and decreasing HDL cholesterol.*
- *The body cannot produce essential fatty acids, so they must be obtained from the diet.*
- *There are two main essential fatty acids, linoleic acid (an omega-6 fatty acid) and alpha-linolenic acid (an omega-3 fatty acid).*
- *Most people consume enough omega-6 fatty acids but often have low intake of omega-3 fatty acids.*

References (see below)

- 1. Vannice G and Rasmussen H. Position of the Academy of Nutrition and Dietetics: Dietary fatty acids for healthy adults. J Acad Nutr Diet. 2014;114:136-153
- 2. Mozaffarian D, Katan MB, Ascherio A and Stampfer MJ. Trans fatty acids and cardiovascular disease. N Engl J Med. 2006; 354:1601-1613
- 5. Surrette ME. The science behind dietary omega-3 fatty acids. CMAJ. 2008; 178: 177-180.

10.4

Digestion and Absorption of Lipids

7.4 Digestion and Absorption of Lipids

Lipids are large molecules and generally are not water-soluble. Like carbohydrates and protein, lipids are broken into small components for absorption. Since most of our digestive enzymes are water-soluble, for digestion to occur and fat to be absorbed, the body has a distinct system for dealing with dietary fat.

From the Mouth to the Stomach

The first step in the digestion of triglycerides and phospholipids begins in the mouth as lipids encounter saliva. The physical action of chewing mixes the food with saliva. The salivary glands produce the enzyme lingual lipase which initiates the process of digestion. Gastric lipase continues the digestive process when the food reaches the stomach. Collectively the effects of these enzymes on fat digestion are small. The majority of fat digestion occurs in the small intestine.

Small Intestine

As stomach contents enter the small intestine, the fats in our food must mix with the water-based digestive fluids through a process called emulsification. Phospholipids present in foods can help with this process, but bile is the primary emulsifier. Bile contains bile salts and phospholipids, which have both hydrophilic (water-attracting) and hydrophobic (water-repelling) regions. These properties allow bile to act like a detergent, breaking large fat droplets into smaller ones so they can be more easily digested and absorbed. Bile is stored in the gallbladder until it is needed in the small intestine (see Figure 6.21).

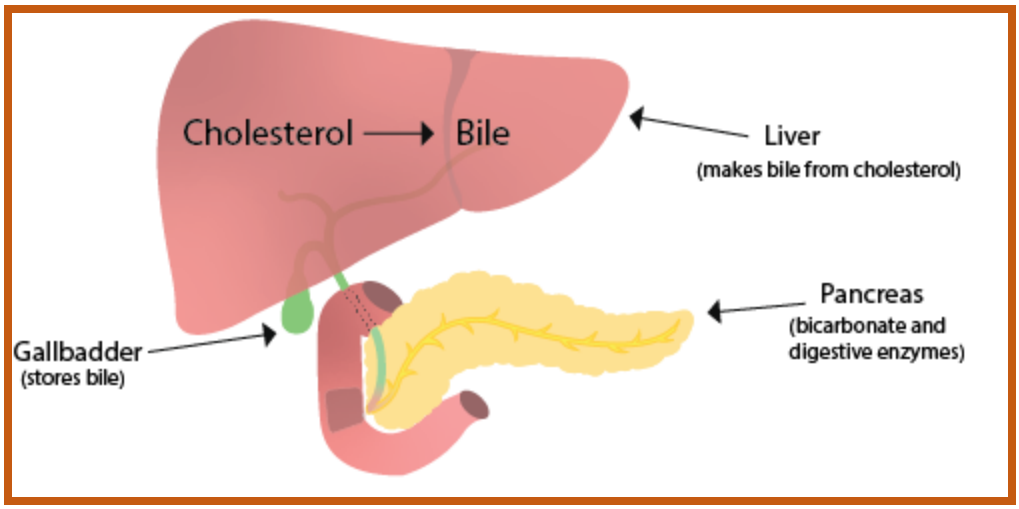


Figure 7.21: The accessory organs and digestion – The liver makes bile, the gallbladder stores bile, and the pancreas produces bicarbonate and digestive enzymes. Photo by Cancer Research UK / Wikimedia Commons under CC BY-SA 4.0 license with edits.

The emulsification of dietary fat by the bile increases the surface area of lipids over a thousand-fold, making them more accessible to the digestive enzymes. The small droplets of fat surrounded by bile are called **micelles** (Figure 7.22).

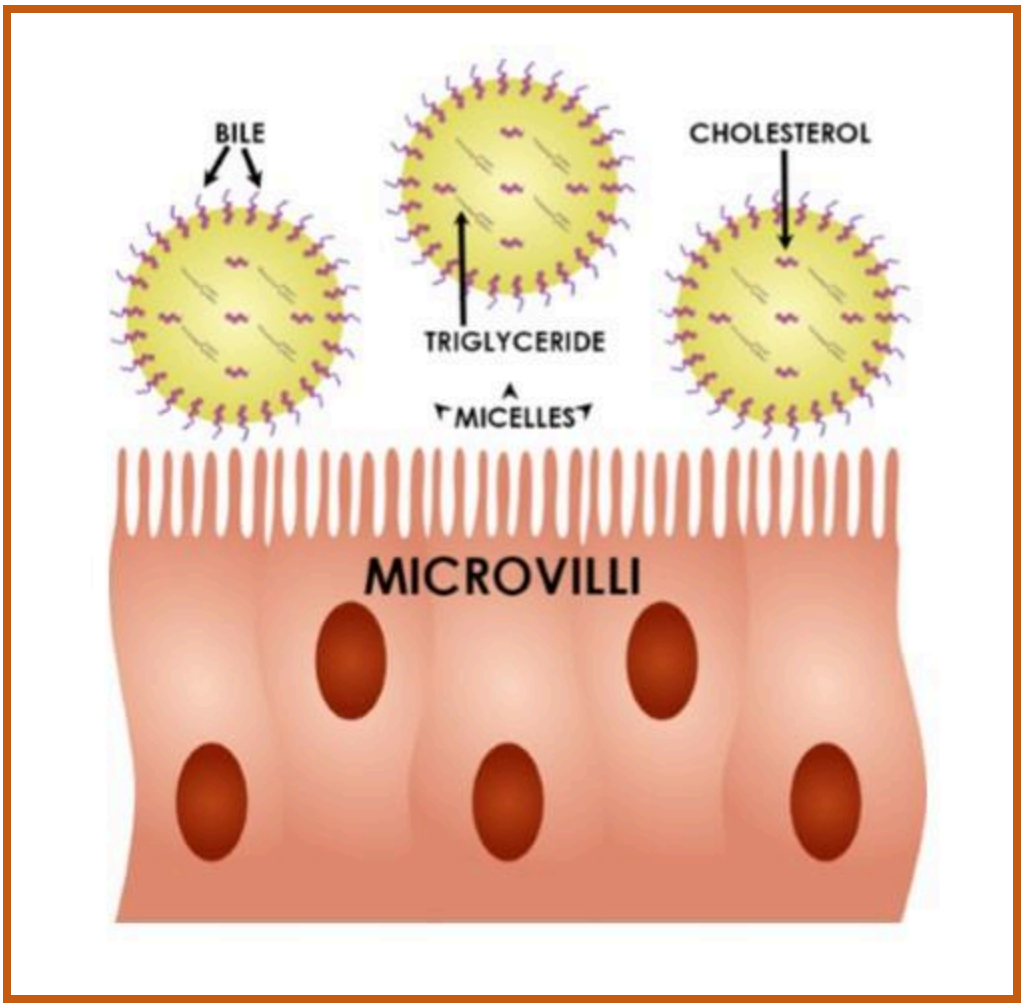


Figure 7.22: Bile and micelle formation

Once the stomach contents have been emulsified by the bile in the small intestine, pancreatic lipase severs fatty acids from the glycerol backbone of triglycerides and diglycerides. The pancreatic lipase ultimately breaks down the triglycerides into free fatty acids and monoglycerides. This in an example of chemical digestion.

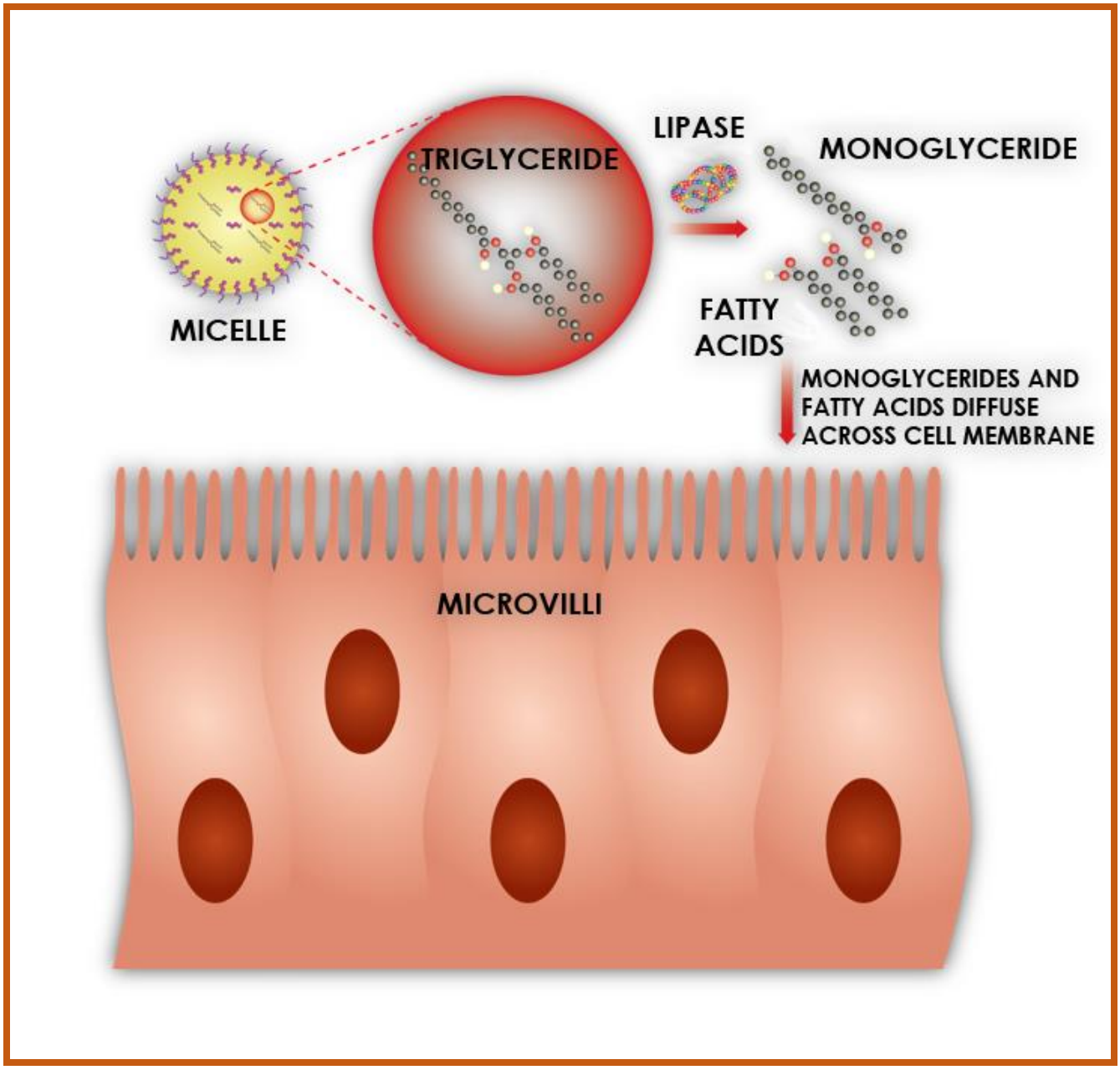


Figure 7.23: Lipid digestion

In the form of free fatty acids and monoglycerides, the dietary fat is now able to be absorbed. The micelles can move to the lining of the small intestine, and the fat components are released and distributed into the cells of the digestive tract lining. Phospholipids follow a similar digestive path as the triglycerides but only require that one of the fatty acids be removed. Cholesterol does not require any chemical digestion to be absorbed.

Transport of Fats in the Blood Stream

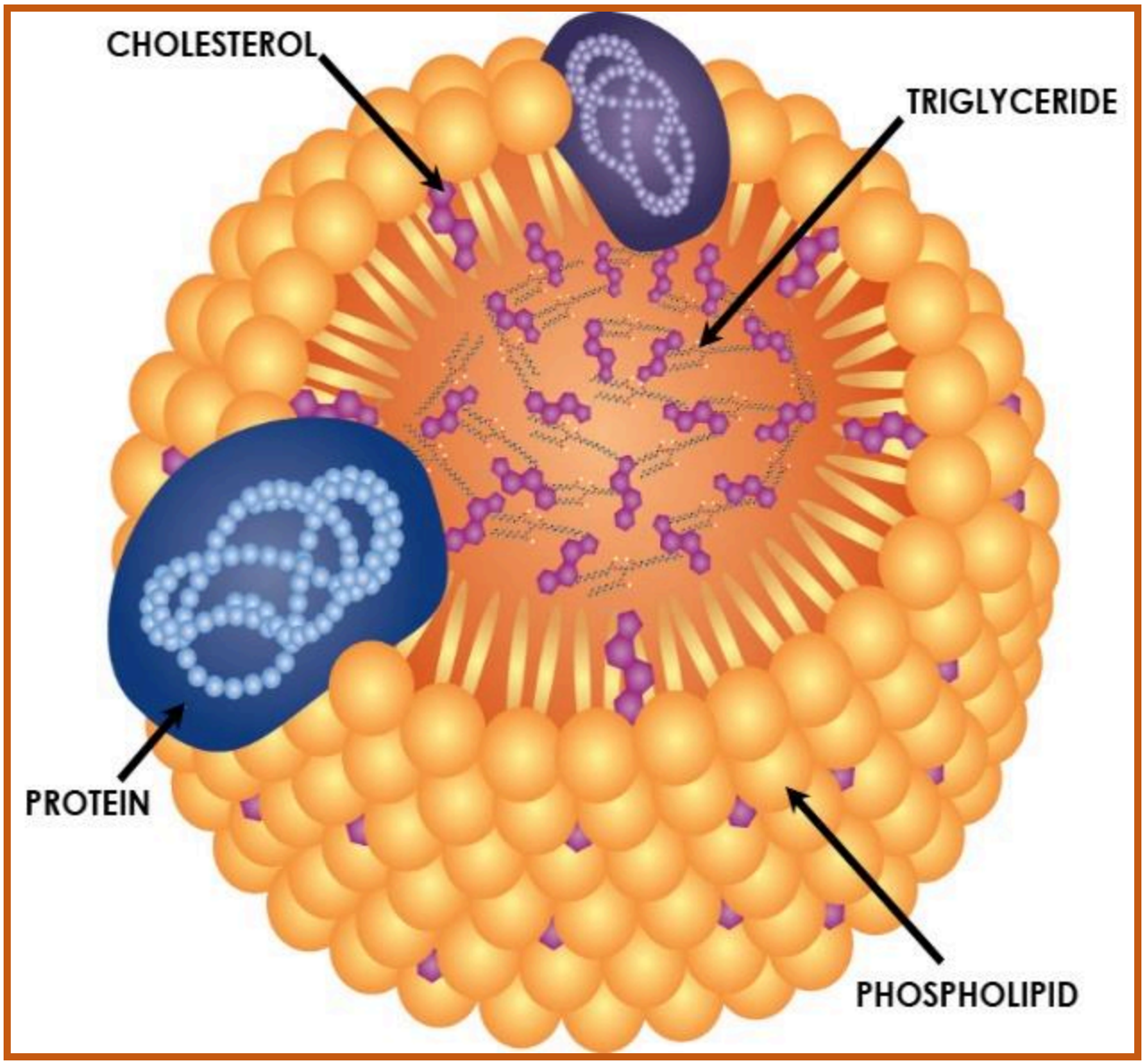
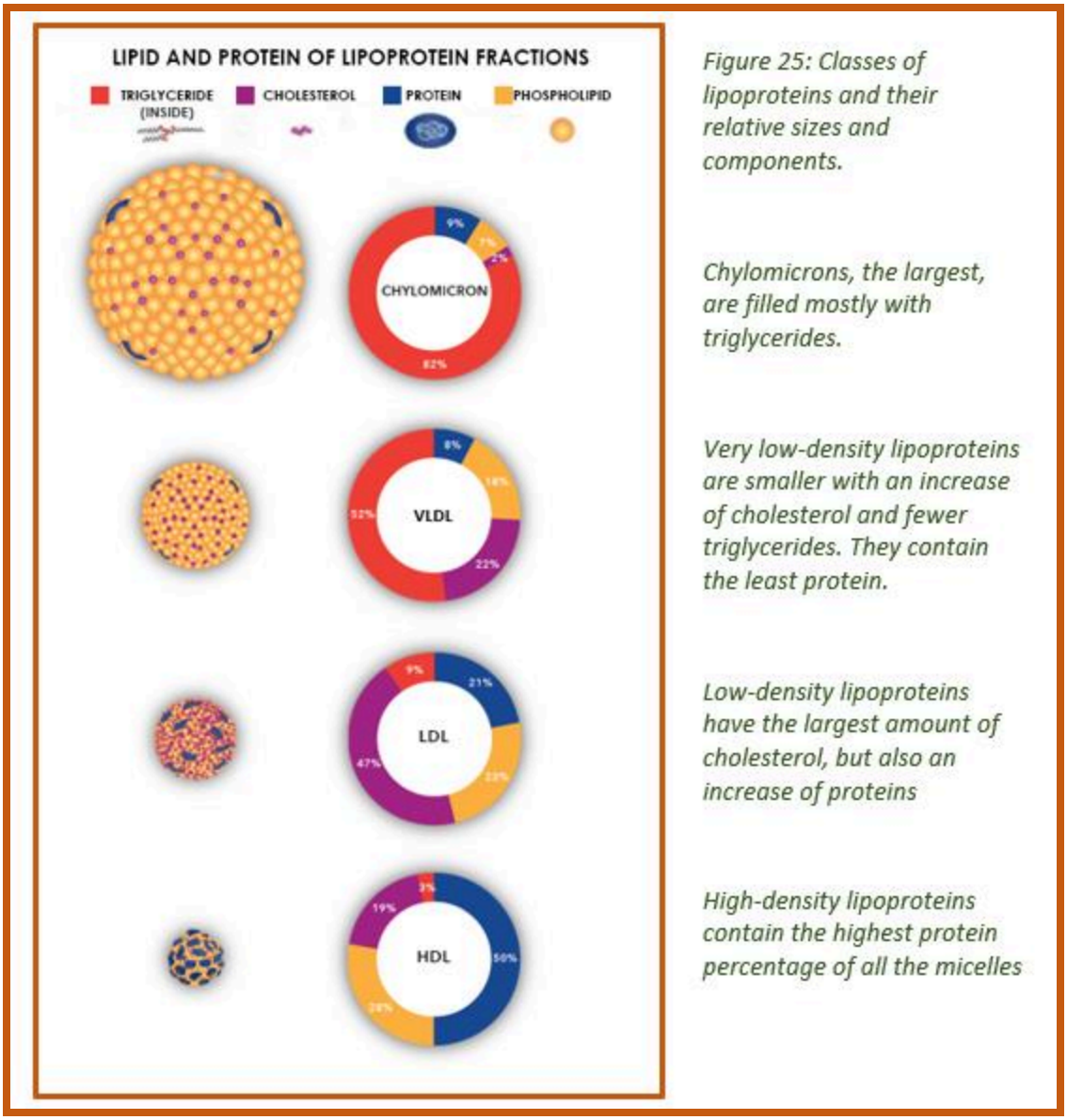


Figure 7.24: Lipoprotein

Inside the intestinal cells, the digested monoglycerides and fatty acids are reassembled into triglycerides and phospholipids and packaged into a lipoprotein called a **chylomicron**. The chylomicron leaves the intestine, enters the lymphatic system, and eventually enters the bloodstream at the thoracic duct, which drains into the left subclavian vein near the neck. Chylomicrons transport dietary fats efficiently through the body's water-based environment. As they circulate, they deliver triglycerides and cholesterol to body cells that need them, such as muscle and adipose tissue. Eventually, the remaining part of the chylomicron, known as the chylomicron remnant, is delivered to the liver.

The liver also produces lipoproteins, but these differ in size and composition from chylomicrons. The main lipoproteins originating from the liver are **very low-density lipoproteins (VLDL)** and **high-density lipoproteins (HDL)**. **Low-density lipoproteins (LDL)** are formed in the bloodstream from VLDL after it has delivered triglycerides to body cells. VLDL and LDL both transport triglycerides and cholesterol to tissues throughout the body. In contrast, HDL helps remove excess cholesterol from cells and transports it back to the liver for disposal or recycling.

Both roles are important and necessary for health. However, problems arise when lipoprotein levels become imbalanced. Elevated levels of LDL are strongly associated with an increased risk of heart attack and stroke, which is why LDL is often referred to as "bad cholesterol." It is important to note that all lipoproteins contain cholesterol, including HDL. Structurally, the cholesterol is the same in each type of lipoprotein. Therefore, it is more accurate to say that having high levels of LDL particles in the blood is harmful, rather than labeling the cholesterol itself as "bad."



Key Takeaways

- *The majority of fat digestion occurs in the small intestine, where bile emulsifies large fat droplets into smaller ones call micelles.*
- *The enzyme pancreatic lipase then breaks down the triglycerides into free fatty acids and monoglycerides, which can be absorbed.*
- *After absorption, dietary fats are packaged into a lipoprotein called a chylomicron for transport from the intestines to the bloodstream and body cells.*

- *The body uses different types of lipoproteins, including VLDL, LDL, and HDL, to transport fats and cholesterol.*
- *LDL is considered "bad" because high levels are associated with heart disease, while HDL is considered "good" because it helps remove excess cholesterol from the body.*

References (see below)

10.5

Functions of Lipids

7.5 Functions of Lipids

Functions of Lipids in the Body

Energy Source

Carbohydrate is often associated with energy for activity. For rigorous activity carbohydrate is indeed a vital fuel, but it can come as a surprise to learn that dietary or stored fat is the primary source of energy for typical daily activities. While **glycogen** (stored carbohydrate) provides a ready source of quick energy, lipids are an excellent stable energy reserve. Glycogen is quite bulky with heavy water content; thus, the body cannot store large amounts. Alternatively, fats are packed together tightly without water and store far greater amounts of energy in a reduced space.

A gram of fat contains more than double the amount of energy (9 kcal/gram) than a gram of carbohydrate (4 kcal/gram). During high-intensity activity the muscles depends largely on carbohydrate, but for typical day-today activities, fat is an excellent dense energy source to fuel muscle activity. The Martin and Willy handcart companies experienced a period of prolonged starvation. Adipose tissue (body fat) would have been a very important supply of energy. Twenty pounds of fat tissue represents a reserve of about 70,000 Calories. For most of us, it is unlikely we will experience prolonged starvation, but during periods of illness, or other physically stressful times, a small reserve of adipose tissue might be helpful. When energy needs are high, dietary fat is also an excellent way to get a lot of calories while minimizing the volume of food needed. For example, certain types of athletes, people who have physically demanding jobs, and those recuperating from serious illness can have high caloric needs. Professional football lineman may require 6000-8000 Calories per day to maintain their weight and activity level. Eating that many calories daily can become difficult. The inclusion of ample amounts of good fats in their diet helps reduce the total volume of food they need to consume.

Conversely, an overabundance of adipose tissue can result in undue stress on the body and be detrimental to your health. A serious impact of excess fat is its association with the accumulation of too much cholesterol in the arterial wall, which can thicken the walls of arteries and lead to cardiovascular disease. Thus, while some body fat is critical for our survival and good health, in large quantities it can be a deterrent to maintaining good health. Because of the high caloric density, a high fat intake can easily lead to over consumption of calories and excess weight gain.



An American football lineman needs more calories than a less active person. Photo by Chris Chow on Unsplash.

"During our sojourn at this camp we were placed under very trying circumstances: being reduced to very low rations of flour, a scanty supply of clothing and in addition to these evils, it became our painful duty to bury very many of our friends and traveling companions" (LDS Church Archives)

Structural and Regulatory Roles

Phospholipids and cholesterol are important structural components of cell membranes. Without these lipids, cells would not exist. The composition of the brain is about 60 percent fat, demonstrating one of the major structural roles that fat serves in the body. Cholesterol also has a key regulatory role as a precursor to important hormones such as estrogen and testosterone. Omega-3 and omega-6 fatty acids give rise to eicosanoids, which influence blood pressure, clotting, and inflammation. The insulation around nerve cells in the brain, called myelin, is also made of fat; without this protective covering, nerve function deteriorates. Adipose tissue plays an additional role in regulation. When fat stores are full, fat cells' production of leptin increases, which under normal circumstances signals to reduce hunger and decrease caloric intake.

Insulation and Protection

Up to 30 percent of body weight is made up of fat tissue. Some of this consists of visceral fat, which surrounds and protects delicate internal organs such as the heart, kidneys, and liver. You may be most familiar with subcutaneous fat, the fat layer found just beneath the skin. This layer insulates the body from extreme temperatures and helps maintain a stable internal



Some handcart companies faced starvation. Photo by Norman Bosworth under GNU Free Documentation License and CC BY-SA 3.0 license.



A snowboarder needs insulation. Photo by Seiya Maeda with unsplash.

temperature. It also provides cushioning for the body during physically demanding activities such as ice skating, roller skating, horseback riding, snowboarding, and skiing.

Bioavailability and Essentiality



Salad with an oil-based dressing. Photo by Dovile Ramoskaite with unsplash.

Some of our essential vitamins and health promoting phytochemicals are fat-soluble. Vitamins A, D, E and K are known as the fat-soluble vitamins. Lycopene (found in tomatoes) is an example of a fat-soluble phytochemical. Often these compounds are found in food containing fat, but not always. For example, a salad with green leafy vegetables, carrots, tomatoes and broccoli contains little fat, but several of these fat-soluble compounds. Consequently, eating salad with an oil-based dressing will increase the absorption of these fat-soluble substances.

Severe deficiency of essential fatty acids is linked to impaired growth, poor skin health, and decreased life expectancy.[1] The inclusion of alpha-linolenic acid (ALA) and linoleic acid have been shown to prevent deficiency symptoms. As a result, they are recognized as essential fatty acids.

Functions of Lipids in Food

Smell, Taste and Texture

Fat contains compounds that create mouthwatering aromas and enhance flavors. It also adds texture to foods, making baked goods tender and moist, and helping fried foods lock in flavor while reducing cooking time. Think about how quickly you can recall the smell of your favorite food cooking. A meal would feel incomplete without these savory aromas that delight our senses and prepare us to eat.



Pastries contain fats that give a rich taste, buttery smell, and flaky texture. Photo by Mink Mingle with unsplash.

Fat also plays an important role in nutrition by contributing to satiety, or the feeling of fullness. When we eat fatty foods, the body slows the movement of food through the digestive tract, which helps us feel full longer. However, this sense of fullness can take time to develop, leading people to overindulge in fat-rich foods because of their irresistible taste. The same qualities that make fat-rich foods so appealing can also make it challenging to maintain a healthy diet.

Tools for Change

While fats provide delicious smells, tastes, and textures to our foods, they also provide numerous calories. To allow your body to experience the satiety effect of the fat before you overindulge, try savoring rich foods. Eating slowly will allow you to both fully enjoy the experience and be satisfied with a smaller portion. Remember to take your time. Drink water in between bites or eat a lower fat food such as fruits and vegetables before and after a higher fat food. The lower fat foods will provide bulk, but fewer calories.

Key Takeaways

- *Lipids are an excellent, calorie-dense energy source (9 kcal/gram), serving as the body's primary fuel for typical daily activities and as a compact energy reserve.*
- *They are essential structural components of cell membranes and nerve insulation, and also have a regulatory role as precursors to hormones.*
- *Body fat provides insulation from extreme temperatures and protects vital internal organs.*
- *The presence of fat is necessary for the absorption of fat-soluble vitamins (A, D, E, K) and other beneficial compounds from food.*
- *In food, fats enhance flavor, aroma, and texture, and contribute to satiety, helping a person feel full after a meal.*

References (see below)

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10.6

Lipids and Health

7.6 Lipids and Health

Heart disease and stroke, two forms of **cardiovascular disease**, remain among the top 5 leading causes of death in the United States according to the CDC. [6] According to the US Department of Health and Human Services (HHS), many of the risk factors associated with the development of cardiovascular disease are controllable such as high blood pressure, high cholesterol, cigarette smoking, diabetes, poor diet, physical inactivity, being overweight, and obesity. [7] This segment of the material will focus on how the selection of dietary lipid can impact some of the risk factors associated with the development of cardiovascular disease.

Cardiovascular Disease

The amount and type of dietary fat selected can have a profound effect on how fat and cholesterol are processed in the body. To understand the link between dietary fat intake and cardiovascular disease risk, it is helpful to consider the roles of the lipoproteins produced in the intestinal tract and liver.

Each of the lipoproteins described in Table 2 below plays an important role in transporting and managing fat and cholesterol throughout the body. Levels of these lipoproteins can be measured through a blood test. Traditionally, people were asked to fast for 9 to 12 hours before a lipid test to reduce chylomicrons in the blood. While non-fasting lipid tests are now widely accepted for routine screening, fasting is still recommended in some cases, especially when triglyceride levels are expected to be high or if previous results were unclear.

Chylomicron levels mainly reflect the fat recently eaten, rather than overall long-term dietary patterns. The goal of a lipid test is to understand total cholesterol, LDL, and HDL levels, which are indicators of long-term dietary and lifestyle habits and directly related to cardiovascular disease risk, not just what someone ate in their last meal.

Lipoprotein	Where it is Produced	Function
Chlyomicron	Gastrointestinal tract	A large particle rich in triglyceride, carries lipids to body cells from the gut

Lipoprotein	Where it is Produced	Function
VLDL and LDL	VLDL is produced in the liver and becomes LDL during circulation	VLDL and LDL are smaller in size than a chlyomicron and serve to carry lipid from the liver.VLDL transport triglycerides to the cells of the body. LDL delivers cholesterol to the cells.
HDL	Produced primarily in the liver	HDL is a small dense particle rich in protein that carries lipid away from body cells back to the liver

Table 2: Lipoproteins produced in the body

Healthy levels of these are described in Table 3. When total cholesterol and LDL are high, and HDL are low, through a complex process involving the immune system, oxidation and inflammation, LDL particles can start to collect underneath the epithelial lining of blood vessels. This is the beginning stages of what is called **plaque**.

	Desirable levels (mg/dl)	Too high or low (mg/dl)
Total Cholesterol	Less than 200	Greater than 240
LDL Cholesterol	Less than 100	Greater than 160
HDL Cholesterol	Greater than 60	Less than 40
Triglyceride	Less than 150	Greater than 200

Table 3: Suggested blood lipid levels[8]

When the lipid deposit gets big enough, the plaque can rupture blocking a blood vessel leading to the heart or brain resulting in an event such as a heart attack or a stroke (see Figure 7.25).

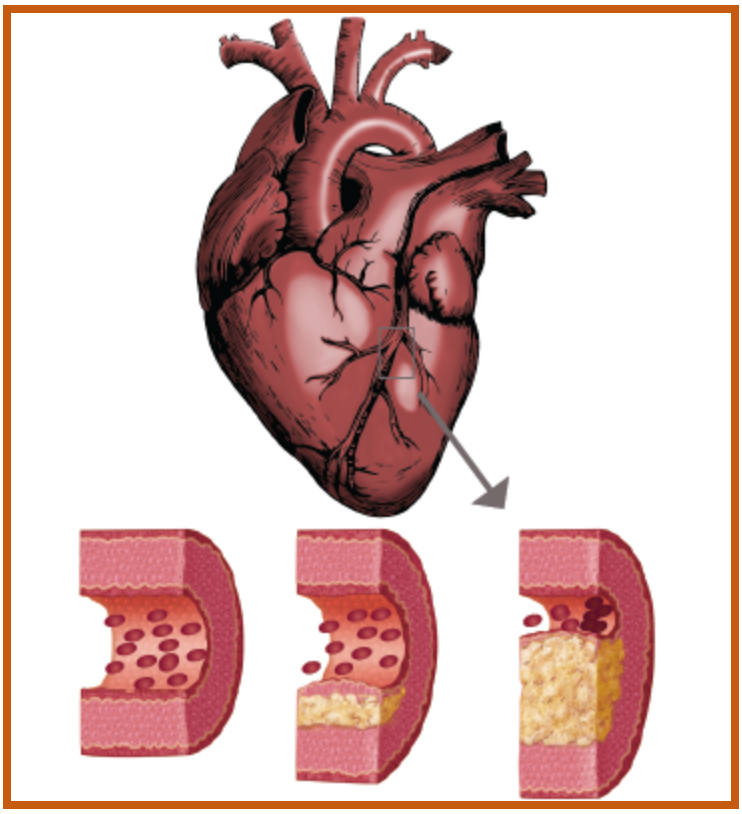


Figure 7.25: Plaque development leading to a heart attack or stroke. Heart image by mandrakept via pixabay. Image by SBCCOE is licensed under CC BY-NC-SA 4.0 with edits.

Key Takeaways

- *Cardiovascular disease is a leading cause of death in the United States, and many of its risk factors, such as high cholesterol and poor diet, are controllable.*
- *The body uses different lipoproteins—including chylomicrons, VLDL, LDL, and HDL—to transport fat and cholesterol through the bloodstream.*
- *LDL is considered "bad" cholesterol because elevated levels can lead to heart attacks or strokes.*
- *HDL is considered "good" cholesterol because it helps remove excess cholesterol from cells and transport it back to the liver for disposal.*
- *A blood test measuring lipid levels (Total Cholesterol, LDL, HDL, and Triglycerides) can indicate long-term dietary and lifestyle habits related to cardiovascular disease risk.*

Reference (see more)

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10.7

Lipid Recommendations

7.7 Lipid Recommendations

Lipid recommendations may vary from organization to organization. Throughout this course, we will focus on the guidelines given in the 2020-2025 Dietary Guidelines for Americans and the Dietary Reference Intakes (DRIs) published by the Food and Nutrition Board. General lipid recommendations are summarized in Table 4. [9]

	Lipid Intake Recommendations
Total Fat as a Percentage of Calories (AMDR)	20-35% of total Calories (adults)
Saturated Fat	Less than 10% of total Calories
Type of Lipid Intake	Replace saturated fat with unsaturated fats increase intake of foods with omega-3 fatty acids

Table 4: Recommended lipid intake [9]

Key Takeaways

- *The recommended daily intake of total fat for adults is between 20-35% of total calories.*
- *Saturated fat intake should be limited to less than 10% of total daily calories.*
- *The guidelines recommend replacing saturated fats with unsaturated fats.*
- *It is also recommended to increase the intake of foods that contain omega-3 fatty acids.*

Reference (see more)

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

10.8

Dietary Lipids and Cardiovascular disease

7.8 Dietary Lipids and Cardiovascular disease

Cholesterol

Surprisingly dietary cholesterol intake is not of primary interest when discussing lipid intake and cardiovascular disease. The liver's ability to increase or decrease cholesterol production can compensate for changes in dietary intake. For most people, cholesterol plays a minor role on lipoprotein levels when compared to other dietary and lifestyle factors. The current Dietary Guidelines for Americans does not list a quantitative value for daily cholesterol intake, but indicates it should be consumed at levels as low as possible without compromising diet quality.[9] It is still an important factor in building a healthy dietary intake, but the principle of moderation should be practiced.

Fatty Acids

Saturated fats

High dietary consumption of saturated fat is associated with increased LDL levels and risk for cardiovascular disease. Saturated fats are found largely in animal products, some plants (such as coconut and palm oil) and many processed foods. Efforts to reduce saturated fat intake for many individuals is an important health consideration. But reducing saturated fat and replacing it with refined carbohydrates or added sugars has been shown to increase disease risk.[10] It is important to replace excess saturated fat with healthy oils or other healthy dietary options such as whole grains products. For example, if you decided to reduce your saturated fat intake by reducing the butter you put on your white bread and rolls by heaping them with jelly instead, this will reduce your saturated fat intake, but is unlikely to improve your health risk. Eating a whole grain piece of bread with a natural nut butter spread would represent a positive dietary change to reduce saturated fat. It is recommended that saturated fat intake be kept under 10% of total calories.[9]

Mono and Polyunsaturated fats

Replacing saturated fat with unsaturated fats has a positive effect on blood lipoprotein levels, total cholesterol, and overall cardiovascular disease risk. Choosing plant oils and foods rich in plant-based fats, such as avocados, olives, nuts, and seeds, instead of saturated fats from animal products and tropical oils, can help lower LDL cholesterol and total cholesterol levels.



Heart-healthy foods include unsaturated fats. Created by AP.

The omega-3 polyunsaturated fatty acids EPA and DHA may support cardiovascular health in unique ways compared to other unsaturated fats. As precursors to eicosanoids, EPA and DHA can help reduce inflammation, lower blood pressure, and decrease blood triglyceride levels. These fatty acids are mainly found in fatty fish like salmon, trout, and sardines. Research supports the health benefits of consuming these fatty acids through fish intake, but the benefits of fish oil supplements remain unclear.

The plant-based omega-3 fatty acid alpha-linolenic acid (ALA) is a precursor to EPA and DHA and can contribute to EPA and DHA levels in the body when consumed regularly through the diet.

Fruits, Vegetables, and Whole Grains

In general, a diet high in fruits, vegetables, nuts and seeds and whole grains is associated with a reduced risk of cardiovascular disease.[11] These types of food choices do contain the good oils that have been discussed, but their positive association with heart health is likely much more involved. These foods are rich in a wide variety of health promoting phytochemicals and fiber. They tend to have a low caloric density and help control obesity which is strongly linked to cardiovascular disease. The Dietary Guidelines for Americans outlines dietary principles consistent with cardiovascular health. The DASH Eating Plan and the Mediterranean diet are good examples of eating styles that reflect heart healthy choices.

Alcohol and Heart Disease

Caloric content

Alcohol contains 7 kcal per gram, and for some people is a significant contributor to daily caloric intake. For example, an average 12-ounce beer contains about 150 calories. If a person were to consume 1 can a day for a year, that would translate to caloric intake of 54,750 calories. If taken in excess of caloric need, in theory that would translate to a weight gain of about 16 lbs.

What constitutes a drink

A standard drink is equal to 14 grams (0.6 ounces) of pure alcohol.[12] Practically, that translates to the following serving sizes of popular types of alcohol containing beverages:

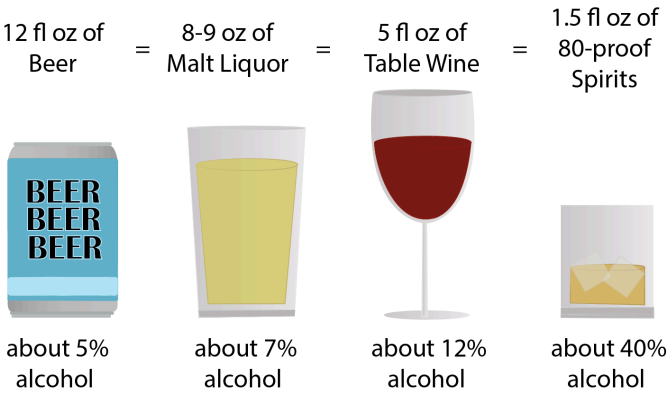


Figure 7.26: What constitutes a drink. Created by AP.

According to the Dietary Guidelines for Americans, **moderate alcohol consumption** is defined as having up to 1 drink per day for women and up to 2 drinks per day for men.[9] This definition is referring to the amount of alcohol consumed on any single day and is not intended as an average over several days. For men, **heavy alcohol consumption** is typically defined as consuming 15 drinks or more per week. For women, heavy drinking is typically defined as consuming 8 drinks or more per week. **Binge drinking** is when men consume five or more drinks, and when women consume four or more drinks, in two hours or less.[13]

Alcohol and health

It is clear that excessive alcohol consumption has devastating effects both in the short and long term. In 2012 roughly 6% of global deaths (3.3 million), were attributed to alcohol use [14,15]. The figure is much higher for 20-39 year olds (25%) [14,15] . The short-term negative effects include errors in judgement. This can lead to problems such as: poor choices, unplanned pregnancies, violence, automobile accidents and alcohol poisoning[15]. For pregnant women, any amount of alcohol intake can lead to immediate damage to the developing fetus, resulting in life long impairment to the child known as fetal alcohol spectrum disorder (FASD). There is no level of alcohol intake that is considered safe during pregnancy. Long-term effects of excessive alcohol use include liver damage, increased risk of some cancers, domestic problems, depression, and cardiovascular disease [15] .

Although a variety of studies have linked moderate alcohol consumption to a reduced risk of cardiovascular disease, and the promotion of moderate alcohol consumption for cardiovascular health has become popular, more recent evidence has shed doubt upon the conclusions drawn from these studies [16,17]. New research links even moderate or light consumption of alcohol with increased risk of some forms of cancer [18,19]. Looking at all these variables collectively, it is clear why the American Heart Association [20] and the authors of the Dietary Guidelines for Americans [9] do not recommend people start drinking for health benefits. Recent scientific evidence validates the wisdom of the council given almost 200 years ago in D&C 89.

Limit	Emphasize
  	  
Keep saturated fat intake less than 10% of caloric intake Minimize trans fat	Choose a diet rich in mono and polyunsaturated fats
Keep added sugar less than 10% of caloric intake	Choose a diet rich in whole grains, nuts, and seeds, fruits and vegetables
Keep sodium intake less than 2300 mg/day	Keep sodium intake less than 2300 mg/day
Limit red meat and processed meats	Consume a calorie level that allows for the maintenance of a healthy weight
If you don't drink alcohol, do not begin. If you do drink alcohol do so in moderation	

Table 5: Summary of key dietary recommendations for cardiovascular health [21] Pizza Image by Thomas Tucker on Unsplash. Bacon Image by Michelle @Shelly Captures It on Unsplash. Brownie Image by Pushpak Dsilva on Unsplash. A Bowl of food Image by Anna Pelzer on Unsplash. Mix of food image by Yu Hosoi on Unsplash. Bread Image by Wesual Click on Unsplash.

Key Takeaways

- *For most people, dietary cholesterol has a minor effect on blood cholesterol levels because the liver can compensate for changes in intake.*
- *High intake of saturated fats is associated with increased LDL cholesterol and cardiovascular disease. These fats should be replaced with unsaturated fats and other healthy options like whole grains, not with refined carbohydrates.*
- *Unsaturated fats, especially omega-3 fatty acids, are considered heart-healthy and can have a positive effect on blood lipoprotein levels.*
- *A diet rich in fruits, vegetables, nuts, and whole grains is associated with a reduced risk of cardiovascular disease.*
- *More recent evidence suggests that even moderate alcohol consumption may not provide cardiovascular benefits and can increase the risk of other diseases, such as cancer.*

References (see more)

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11

Chapter 11: Energy Balance

11.1. Evaluating Body Weight

11.2. The Energy Balance Principle

11.3. Additional Factors

11.1

Evaluating Body Weight

11.1 Evaluating Body Weight

Weight and Health

Many people want to reach a healthy weight. Information in the media, however, often gives confusing messages about what constitutes a healthy weight. Social and cultural standards can influence the perception of “ideal” body weight. Also, reports of increasing obesity and a clear presence of underweight individuals across the world raise questions about the health concerns of too much or too little body weight.[1,2] With all of this conflicting information, it can be hard to understand what is meant by the term “ideal weight.”



Figure 11.1: The body is compared to a temple. Image by Dustin Humes on Unsplash.

The scriptures and modern-day revelation teach that the physical body is a gift from God.

1 Corinthians 3: 16-17 Know ye not that ye are the temple of God, and that the Spirit of God dwelleth in you… for the temple of God is holy, which temple ye are.[3]

Just as each temple is unique, physical bodies have many distinct attributes. A healthy weight is determined by more than just appearance or a number on a scale. Individual traits, such as height, gender, age, sex, frame size, and body composition contribute to what constitutes a healthy weight for each individual. [4]

There are many methods for assessing body weight and its impact on health and disease risk.

The major components of body weight are water, muscle mass, bone mass, and fat mass. Having more weight than is common for a particular height can be the result of water weight, muscle weight, or fat mass.[5] The terms overweight and obesity refer to an abnormal or excessive fat accumulation that may impair health.[6] Therefore, body weight can be a sign of obesity in many people. Having too much body fat can increase the risk of certain diseases and decrease quality of life. [1] In contrast, having a low body weight can also be detrimental to health. Figure 1 outlines potential concerns of too much body fat or a low body weight. [7]

Too Much Body Fat Is Associate With An Increased Risk Of:	Having a Low Body Weight Is Associated With An Increased Risk Of:
• High blood pressure • Heart disease and stroke • High cholesterol • Insulin resistance and type 2 diabetes • Hormone imbalances • Gallbladder disease • Osteoarthritis • Some types of cancer (breast, colon, liver, and others • Infertility • Sleep apnea and breathing problems • Mental illness (depression, anxiety, and others)	• Reduced bone density • Increased risk of fractures • Low vitamin and mineral stores • Infant mortality • Infertility • Hormone imbalances • Reduced immunity, increased illness • Low birth weight and stunting in infants and children

Figure 11.2: Health consequences of too much body fat and low body weight[1,2]

Scientists have developed a variety of formulas that utilize measurements such as height, weight, age and waist and hip circumference to estimate a healthy weight for an individual. Health professionals use these types of equations to assess disease risk in individuals and populations. [8] In general, body mass index (BMI) is a good tool to use when looking at disease risk in populations. However, because BMI has some inherent problems, it is not a good tool to use to strictly define whether or not an individual person is at a healthy weight. However, because it only requires a height and weight, it is a quick and easy way to begin looking at a person's relative risk for some chronic diseases.

BMI

Body mass index (BMI) is calculated using height and weight measurements. BMI measurements are used to classify whether an individual may be underweight, at a healthy weight, overweight, or obese. Classification of these weight categories are determined differently for adults and children (see Table 1). [9,10] High BMI measurements can be warning signs of disease risks associated with too much body fat.1 BMI-associated disease risks vary by race. For example, an Asian person with a BMI of 30 faces a greater disease risk than a Caucasian person with the same BMI. And a Caucasian person with a BMI of 30 faces a greater disease risk than an African American with a BMI of 30.

Calculating BMI

BMI = [weight (kg)] ÷ height (m)2

or

BMI = [weight (pounds) x 703] ÷ height (in)2

(to square height, multiply it by itself)

A low BMI can be a warning sign of disease risk associated with too little body mass. Low BMI can be an indication of malnutrition especially in underserved populations such as the elderly, the homeless and refugees. A low BMI can also be associated with eating disorders. Hospitalized patients with a low BMI have longer hospital stays, have a greater fall risk, greater infections rates and higher risk of mortality.

To calculate your BMI, divide your weight in kilograms by your height in meters squared. BMI can also be calculated using weight in pounds and height in inches with a conversion factor.[8]

BMI Category	Children & Adolescents (ages 2-19 years) (BMI-for-Age Percentile)	Adults (BMI)
Underweight	Less than the 5th percentile	Less than 18.5 kg/m^2
Healthy Weight	5^{th} to < 85^{th} percentile	18.5 - 24.9 kg/m^2
Overweight	85^{th} to < 95^{th} percentile	25.0-29.9 kg/m^2
Obese	Greater than or equal to the 95^{th} percentile	30.0 kg/m^2
Extreme Obesity	-	40.0 kg/m^2 or greater

Table 11.1: BMI Categories[9,10]

BMI is a fairly simple measurement but does not take into account fat mass or fat distribution in the body, both of which are predictors of disease risk. Contrary to popular belief, muscle does not weigh more than fat. One pound of muscle weighs exactly the same as one pound of fat, but they take up different amounts of space. The pound of fat takes up more space than the pound of muscle. For example, one pound of feathers and one pound of lead weigh exactly the same, but the pound of feathers takes up much more space than the pound of lead. Therefore, BMI can sometimes incorrectly categorize a person as overweight or obese.[11] For example, a muscular athlete will have more muscle mass (which is heavier than fat mass in the same volume area) than an inactive person with less muscle mass, of the same height. Based on their BMIs the muscular athlete may be categorized as more overweight or obese than the inactive person. Additionally, an older person with osteoporosis (decreased bone mass) will have a lower BMI than an older person of the same height without osteoporosis, even though the person with osteoporosis may have a greater fat mass.[11] Because BMI only requires height and weight it is an easy and inexpensive tool to use in public health to reflect a person's disease risk; however, other measurements are needed to more accurately assess health risk for the individual.



Figure 11.3:Weightlifters can have a high BMI for their weight. Image by Vido Boskovic on Pexels.

Monitoring Children's Weight

BMI charts were designed to help track weights of children. To calculate a BMI for a child, you would use height and weight as you would for adults. However, because children grow at different rates at different stages, we need to look at more than the calculated BMI number alone. We need to plot the BMI on a chart to identify the percentile to assess their weight status.[12] The percentile (color coded in Figure 2) gives us more information than the BMI alone. BMI charts are available by gender and for various age ranges. Figure 2 is an example of a BMI chart for a boy between 2 and 20 years of age.

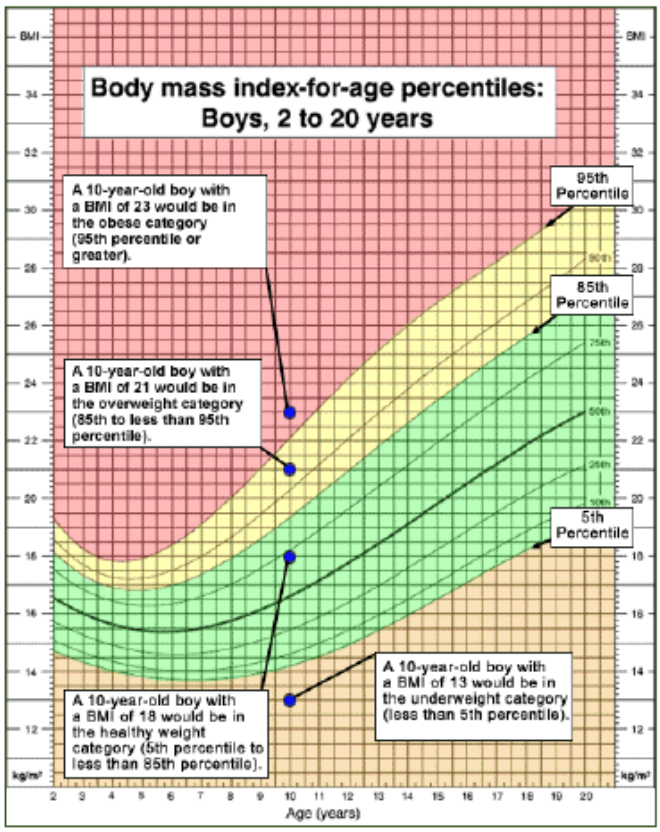


Figure 11.4:Examples of how to use BMI for children and plotting on the BMI growth chart. [12]

Body Composition

Body composition includes the water, organs, bone, fat, and muscle tissue that make up a person's weight.[5] Having more fat mass may be a sign of disease risk, but fat mass also differs with sex, age, and physical activity level. Females have more fat massthan males, which is needed for reproduction and, in part, is a result of different levels of hormones.



Figure 11.5: Measuring skin with calipers. Image by AL.

Percent body fat is the amount of fat in the body compared to other tissues. Healthy body fat percentage for a female is considered to be between 20 and 30 percent of her total weight and for a male is between 12 and 20 percent.[13] Fat mass or percent body fat can be measured or estimated in a variety of ways, as outlined below.

Skinfold Thickness

A health professional uses a caliper to measure the thickness of skin on the back, arm, and other parts of the body and compares it to standards to assess body fatness. This test measures subcutaneous fat, which is the layer of fat just beneath the skin. It is a simple and quick method of measuring fat mass in a specific area of the body, but it can be less precise than other methods in estimating total body fat.[14] Similar to BMI, skinfold thickness is compared to standards created from measurements of mostly young to middle-aged adults.

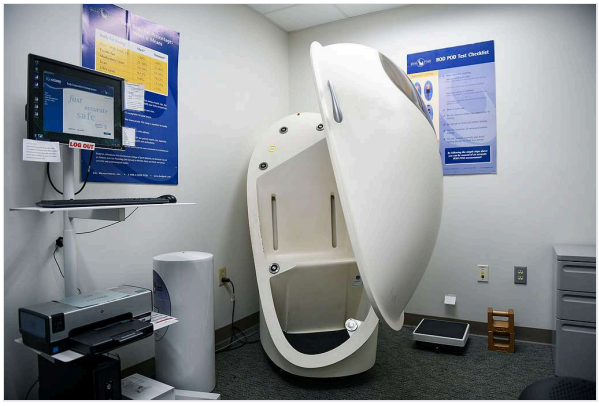


Figure 11.6: A Bod Pod used to measure body composition. Image by Airman 1st Class Joshua T. Crossman on picryl.

Air Displacement

Body composition can be measured using air displacement. A Bod Pod is a high tech piece of equipment that has a compartment big enough for a person to sit in. Once inside the compartment, computerized pressure sensors determine the amount of air displaced by the person's body.

Water Displacement

Due to the fact that bone and muscle are denser than fat, underwater weighing can be used to determine a person's body composition. To obtain an underwater weight, a person is weighed on dry land, then placed into a large tank of water with a special scale. They are weighed again while submerged underwater. Fat is less dense and therefore more buoyant (able to float) than muscle and bone. Because of buoyancy, fat weighs less than muscle and bone underwater. Using a mathematical equation, the percent body fat of a person can be calculated by comparing their dry land weight and their underwater weight. Underwater weighing uses specialized equipment. The person being weighed must be able to hold their breath for an extended period of time.

For healthy adults, both underwater weighing and air displacement, rate high in accuracy and precision of determining body composition in comparison to other techniques. However, both are expensive and not readily available for most people. Given a choice, many people prefer air displacement to underwater weighing because they don't have to be submerged, or hold their breath.[14]

Bioelectric Impedance Analysis (BIA)

BIA assess body fat percentage by measuring resistance of tissues to a small electric current that is run through the body.[14] The amount of water in the body affects the flow of the current. Because certain tissues, such as fat and bone, contain very little water, they slow the flow of the electrical signal. When the small amount of electricity is passed through the body, the rate at which it travels is used to estimate body composition. Mathematical equations are used to estimate fat mass. These equations take into consideration individual characteristics such as age, height and disease state. Body composition scales,

which incorporate BIA technology, are now available for home use. These devices make measuring body fat easy and inexpensive. However, accuracy and precision of this technique can be negatively affected by variations in food intake, hydration and other factors.[15]

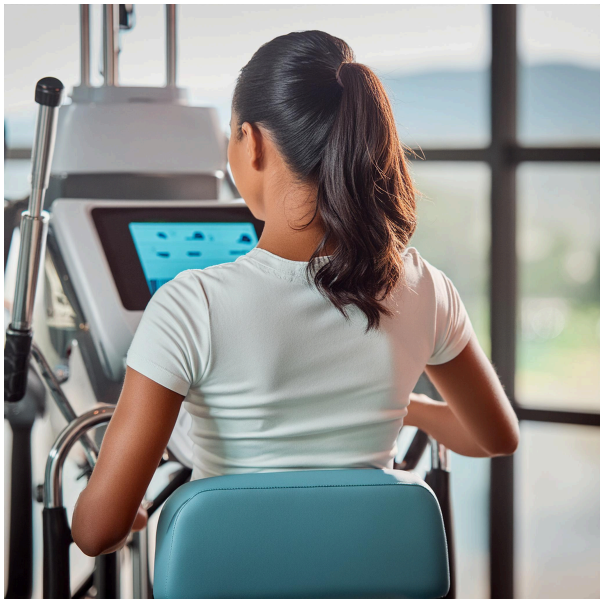


Figure 11.7: BIA Test. Image by AL.

Dual-Energy X-Ray Absorptiometry (DEXA)



Figure 11.8: Doctor scanning patient using DEXA machine. Image by valelopardo on Pixabay.

This method is commonly used to measure bone density, but it can determine fat content from a full body scan. Two low-dose xray beams are directed through the body and the amount of the energy absorbed from the beams is determined.[14] The amount of energy absorbed is dependent on the body's content of bone, muscle mass, and fat mass. Using standard mathematical formulas, fat content can be accurately estimated. While this tool is expensive and does expose subjects to a low dose of radiation, it is considered one of the most reliable ways to measure body fat composition.[14,16]

Fat Distribution

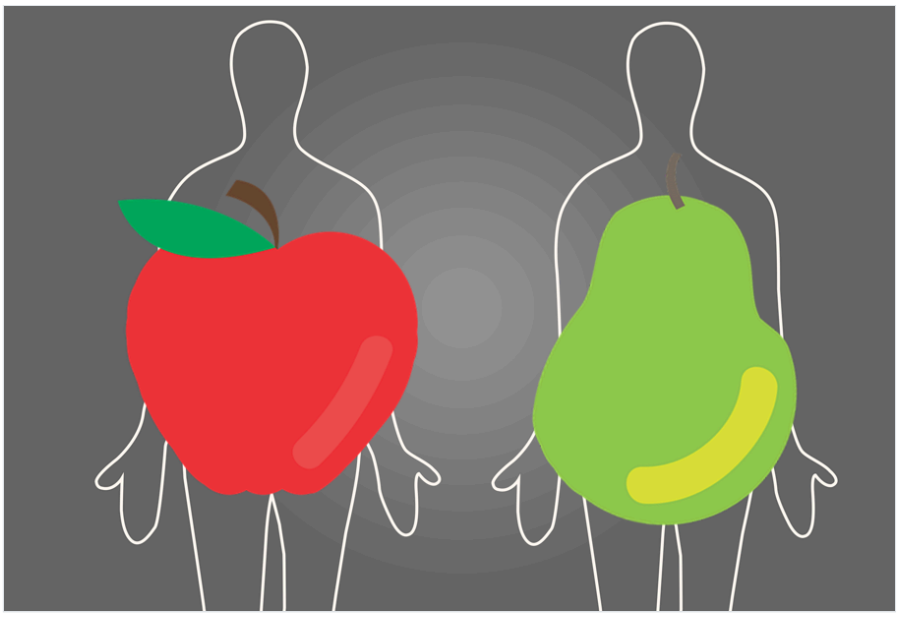


Figure 11.9: "Apple" shape with weight in abdomen, and "pear" shape with weight on hips. Image by AL.

Total body-fat mass is one predictor of health; another is body fat distribution. You may have heard that fat on the hips is healthier than fat in the belly—this is true. Observational studies have demonstrated that people with "apple-shaped" bodies, (those who carry more weight around the waist) have greater risks for chronic disease than those with "pear-shaped" bodies, (those who carry more weight around the hips).[3] Fat can be found in different areas of the body and it does not all act the same way. Fat can have a different physiological effect, depending on its location. Fat deposited in the abdominal cavity is called visceral fat and it is a better predictor of disease risk than total fat mass.[5] Visceral fat contributes to the apple shape, while subcutaneous fat contributes to the pear shape. Visceral fat releases hormones and inflammatory factors that contribute to disease risk. Waist measurement can be used to estimate visceral fat. The only tool required is a measuring tape. The measurement of waist circumference is taken just above the belly button. Men with a waist circumference greater than 40 inches (102 centimeters), and women with a waist circumference greater than 35 inches (88 centimeters), are predicted to face greater health risks.[17]

Extremely High Risk	Very High Risk	High Risk	Increased Risk	Low Risk
BMI≥40.0 High waist circumference	BMI 30.0-39.9 High waist circumference	BMI 25.0 - 29.9 High waist circumference	BMI 25.0 - 29.9 Low waist circumference	BMI <25.0

Table 11.2 Health risk associated with BMI and waist circumference Adapted for the National Institutes of Health[10]

An additional measure of fat distribution is the waist-to-hip ratio.[18] To calculate a waist-to-hip ratio, use a measuring tape to measure waist circumference and then measure hip circumference at its widest part. Next, divide the waist circumference by the hip circumference to arrive at the waist-to-hip ratio. Abdominal obesity, which can be predictive of disease risk, is defined by the World Health Organization (WHO) as having a waist-to-hip ratio above 0.90 for males and above 0.85 for females.[18]

Key Takeaways

- *A healthy body weight is determined by more than just a number on a scale and is influenced by individual factors such as height, age, gender, and body composition.*
- *Body Mass Index (BMI) is a simple calculation of height and weight that is useful for assessing disease risk in large populations, but it has limitations for individuals because it does not account for muscle mass or fat distribution.*

- *The distribution of body fat is a major predictor of health. An "apple shape" (for fat in the abdominal area) is associated with a greater risk of chronic diseases than a "pear shape" (more fat in the hips).*
- *Both having too much and too little body fat are associated with significant health risks, including a higher risk for chronic diseases, hormone imbalances, and reduced immunity.*
- *There are various methods to measure body composition, ranging from simple techniques like waist circumference and skinfold thickness to more accurate but expensive methods like DEXA scans and air/water displacement.*

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11.2

The Energy Balance Principle

11.2 The Energy Balance Principle

Obesity

Over the past 25 years more than 50% of the U.S. adult population has been overweight or obese (see Figure 3).[19] Lifestyle behaviors related to poor eating habits and physical inactivity have resulted in 117 million adults with preventable chronic diseases in the United States.[20] The World Health Organization refers to obesity as a neglected public health problem and a global epidemic.[21] In 2016, almost 13% of adults across the world were obese and 39% were overweight.[22] Over the past 40 years, the incidence of obesity has more than doubled worldwide.[22] Additionally, over the past 30 years, there has been a rise in overweight and obesity in children and adolescents.[22]

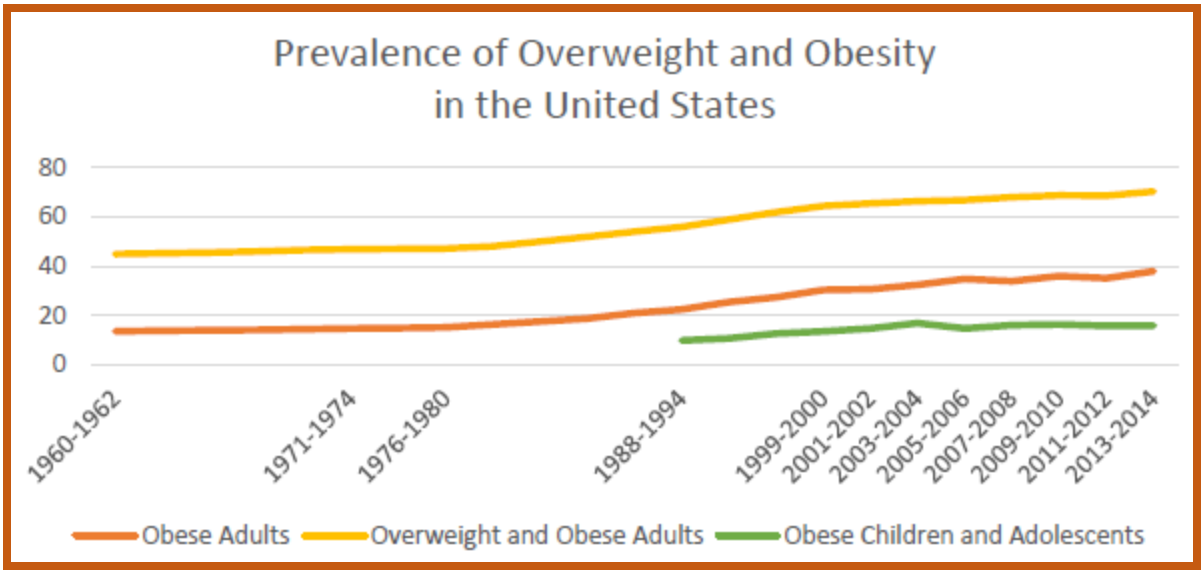


Table 11.3: Prevalence of Overweight and Obesity in the U.S. Adapted from the Centers for Disease Control and Prevention (NHANES Data)[21,22]

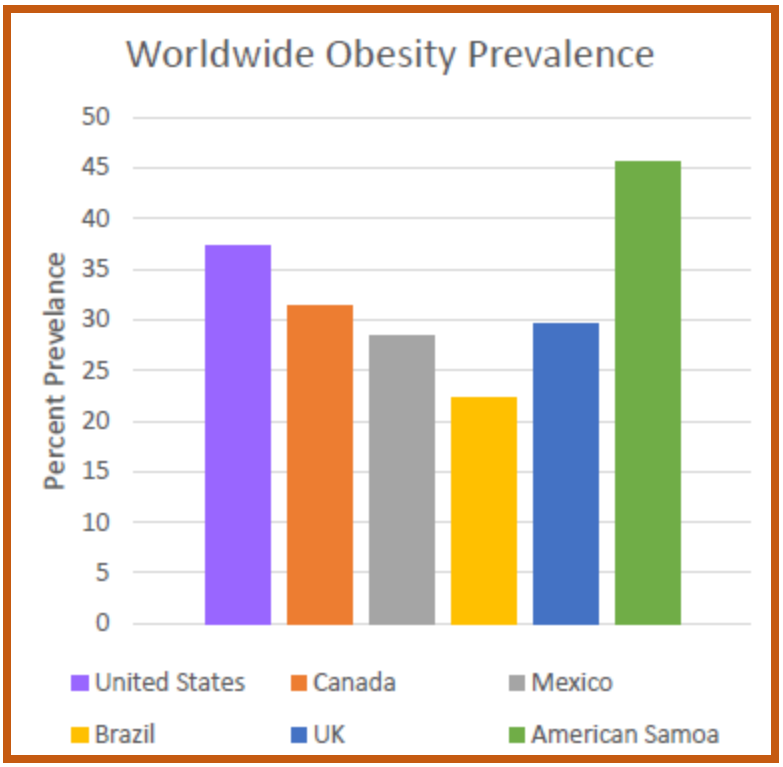


Table 11.4 : 2016 Obesity Prevalence – Adapted from the World Health Organization [22]

These trends are likely due to environmental and societal changes associated with modern development. Around the world, dietary habits have changed to include increased intake of ultra-processed foods that are high in fat, sugar, and calories. Advances in working conditions and modes of transportation have led to the development of a more sedentary lifestyle for many people.[22] In many developing countries, where underweight and malnutrition has been a primary concern historically, there is an alarming increase in the incidence of overweight and obesity due to these types of changes in lifestyle and diet[23]

Over time as energy intake exceeds energy expenditure, weight gain occurs. This energy imbalance is often the cause of fat accumulation leading to the development of overweight and obesity.[22]

The World Health Organization reports that while roughly 1.9 billion adults are overweight or obese there are over 460 million that are underweight globally. There are many reasons that an individual may be underweight. Medical illnesses that may impact metabolism or food intake, medications that suppress appetite or cause mouth sores that make it difficult to eat, or psychological issues such as anorexia nervosa are a few examples. But, by far the most prevalent reason for the high incidence of underweight globally is simply the limited access some have to adequate amounts of food to meet caloric needs. Forty-five percent of deaths in children under 5 are linked to undernourishment.[2]

Energy Balance

People gain, maintain, or lose weight as a result of the balance of energy intake and energy expenditure. Energy is measured in calories. Energy intake includes calories consumed by eating and drinking. Energy expenditure includes calories burned through basal metabolism (energy needed for basic body function), physical activity, and the thermic effect of food (energy used to digest and absorb foods).[7] Energy balance occurs when energy intake is equal to energy expenditure. Negative energy balance occurs when energy intake is less than what the body needs, leading to weight loss. Positive energy balance occurs when energy intake is more than what the body needs, leading to weight gain (see Figure 6). These weight changes do not happen overnight, but rather they occur in response to calorie imbalance over time.[24]



Figure 11.10: Energy Balance Concept[24]

Even small changes in energy balance, as little as 100 to 200 Calories per day, can support weight management. For weight loss, reducing intake by 100 to 200 Calories might include cutting back on sugar-sweetened beverages, eating smaller portions at meals, or increasing energy expenditure is also effective such as going for a walk or bike ride. Similarly, weight gain can be achieved by increasing food intake.[24,25]

Energy Intake

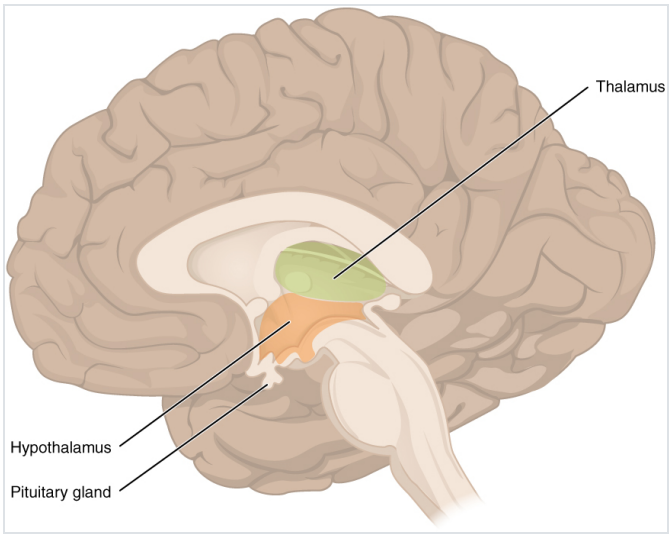


Figure 11.11:The hypothalamus controls energy balance. Image by OpenStax under CC BY 4.0 license.

The **estimated energy requirement (EER)** approximates the recommended amount of calories that should be consumed on a daily basis to maintain a healthy body weight. To calculate EER, standard equations are used that factor in gender, age, height, weight, and activity level, all of which affect a person's energy needs.

EER = 662 – (9.53 x Age in years) + {PA x [(15.91 x weight in kg) + (539.6 x Height in meters)]}

Energy intake is influenced by individual desires, physiological needs, and even genetics. The hypothalamus in the brain is responsible for regulating food intake and maintaining food intake.[26] **Hunger** is a signal the body sends to promote eating. This signal is triggered by emptiness of the stomach, changes of blood nutrient levels and other physiological changes, which stimulates the release of hormones and stomach contractions. These stomach contractions often result in the familiar "growling" stomach. **Appetite** is a desire for food that is independent of hunger.[26] For example after a large meal, we may still have an interest in a favorite dessert despite the lack of any physical signals indicating the presence of hunger. The desire to eat when we are not hungry is referred to as appetite.

Energy Expenditure

Energy expenditure is made up of basal metabolism, physical activity, non-exercise activity thermogenesis (NEAT), and the thermic effect of food.[4] **Basal metabolism** includes the energy for basic needs, specifically involuntary functions such as blood circulation, breathing, maintenance of body temperature, cell/tissue growth, and other body functions. On average, energy needed for these processes makes up 60% of total energy expenditure. Basal metabolism

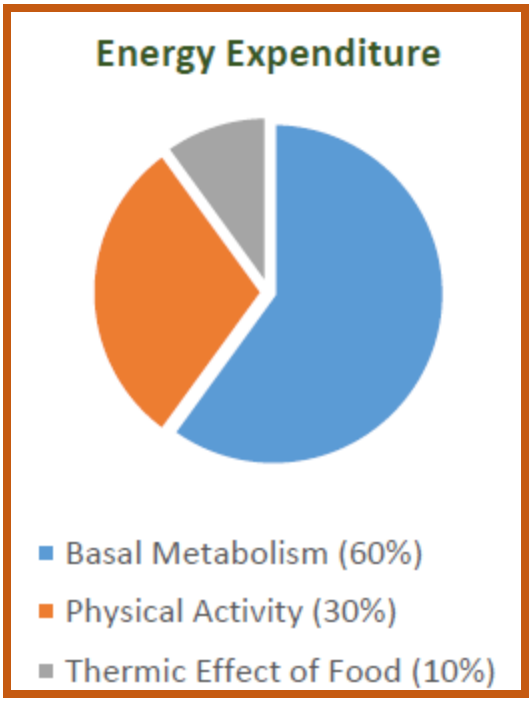


Table 11.5: Energy Expenditure - Adapted from the Academy of Nutrition and Dietetics[4]

is typically measured while some one is fasted, and in a completely rested state, but while awake. The basal metabolic rate (BMR) can be affected by age, gender, genetics, and body composition. This is why two people of the same age, height, and activity levels can have significantly different experiences with weight management.[4]

Physical activity includes any voluntary movement, such as walking, climbing stairs, or jogging. About 30% of total energy expenditure on average is used for physical activity, but this estimate varies greatly depending on how active a person is. More active individuals have a higher percentage of their energy expenditure coming from physical activity compared to sedentary individuals.[4] Unlike basal metabolic rate, which is relatively fixed, physical activity is the component of energy expenditure that can be most easily increased to raise daily caloric burn.

NEAT is the abbreviation for non-exercise activity thermogenesis. It includes activity that is not formal exercise (playing basketball) or resistance training activities (working out at the gym etc.). For many people, NEAT is a significant contributor to their daily energy expenditure above the basal rate.[27,28] NEAT includes common activities such as walking around the house (or store or office), climbing stairs, cleaning, standing (rather than sitting) and even fidgeting and gum chewing. Energy expenditure from NEAT can add up to significant amounts. Sedentary individuals may only expend 15% of their total daily energy expenditure as NEAT, whereas active individuals may exceed 50%. This type of energy expenditure has gained interest in the scientific community. Research has shown increased NEAT expenditure has positive effects on weight maintenance, successful weight loss, as well as reduced risk for chronic disease.[27,28] Small changes in daily routines can enhance energy expenditures and can positively impact health. The benefits of regularly planned formal exercise is well documented. NEAT activities are not a replacement for formal exercise or resistance training, but instead are an additional source of energy expenditure.

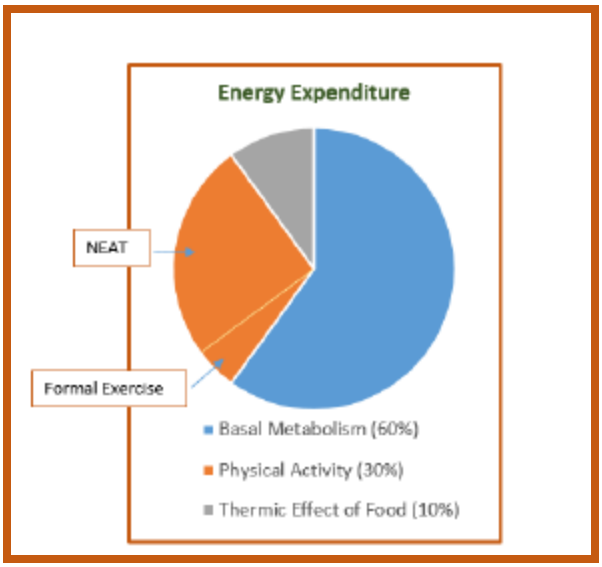


Table 11.6: Energy expenditure from NEAT

The energy needed to digest food and absorb nutrients is called the **thermic effect of food (TEF).** Eating and digestion makes up about 10% of daily energy use.[4]

Key Takeaways

- *Globally, there is a significant growing problem of overweight and obesity, largely due to changes in diet and an increase in sedentary lifestyles. However, a high prevalence of underweight individuals persists, often due to limited food access.*
- *Weight gain, loss, or maintenance is governed by the energy balance principle, which states that the balance calories consumed (energy intake) and calories burned (energy expenditure) over time determines changes in body weight.*
- *Energy expenditure is composed of four parts: basal metabolism (the largest portion for basic body functions), physical activity, the thermic effect of food (for digestion), and non-exercise activity thermogenesis (NEAT).*
- *NEAT is the energy burned from daily, non-exercise movements like fidgeting or standing and can be a significant contributor to a person's total daily energy expenditure.*
- *Hunger is the body's physiological need for food, while appetite is a desire for food that is independent of physical hunger.*

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11.3

Additional Factors

11.3 Additional Factors

After considering the role that energy intake and energy expenditure play in weight management, it is important to consider other factors that may contribute to the development of obesity.

Genes

Genetics play a significant role in determining body weight and fatness. It is estimated that 40–70% of the variation in BMI among individuals can be attributed to genetic factors. Evidence supporting this comes from studies of adopted children, whose BMIs more closely resemble those of their biological parents than their adoptive parents. Additionally, identical twins are about twice as likely to have similar body weights compared to fraternal twins.

Researchers have identified specific genes associated with an increased risk of obesity, many of which influence appetite and food intake. For instance, genetic variations that impair the production or function of leptin—a hormone that signals fullness—can result in increased hunger and food consumption.

However, obesity is not caused by a single gene. Rather, it reflects the complex interaction of hundreds of genes with environmental factors. Fortunately, even individuals who carry genes linked to obesity can reduce their risk through healthy lifestyle choices and environmental management.

Hunger Hormones: Ghrelin and Leptin

Hormones are clearly linked to hunger and satiety which can affect weight status. The levels of certain hormones influence when a person desires food or feels satiated (feels full).



Figure 11.12: Obesity has a genetic component. Image by AL.

Ghrelin is often referred to as the “hunger hormone.” It is produced and secreted by the stomach and travels through the bloodstream to the brain, where it signals the hypothalamus to increase hunger. Ghrelin levels rise when a person hasn’t eaten, stimulating appetite, and decrease after eating.

Leptin, in contrast, is a hormone produced by adipose (fat) tissue. Like ghrelin, it travels through the bloodstream to the brain but signals the hypothalamus to reduce hunger. When fat stores are sufficient, more leptin is released, which tells the brain that energy reserves are adequate and helps suppress appetite.

In individuals with obesity, leptin resistance may develop. This means that even though leptin levels are high, the brain does not respond appropriately, and hunger is not suppressed as it should be. Similarly, abnormally high ghrelin levels or low leptin levels can lead to increased hunger and reduced satiety. Over time, these disruptions in hormonal signaling can contribute to excessive caloric intake and weight gain.

Key Takeaways

- *Genes play a significant role in determining body weight, accounting for an estimated 40-70% of the variation in BMI among individuals.*
- *Obesity is a complex condition resulting from the interaction of multiple genes with environmental factors, meaning that healthy lifestyle choices can still help reduce risk even for those with a genetic predisposition.*
- *Ghrelin, often called the "hunger hormone," is produced by the stomach and signals the brain to increase appetite, with levels rising when a person has not eaten.*
- *Leptin is a hormone secreted by fat tissue that signals the brain to reduce hunger and promote satiety.*

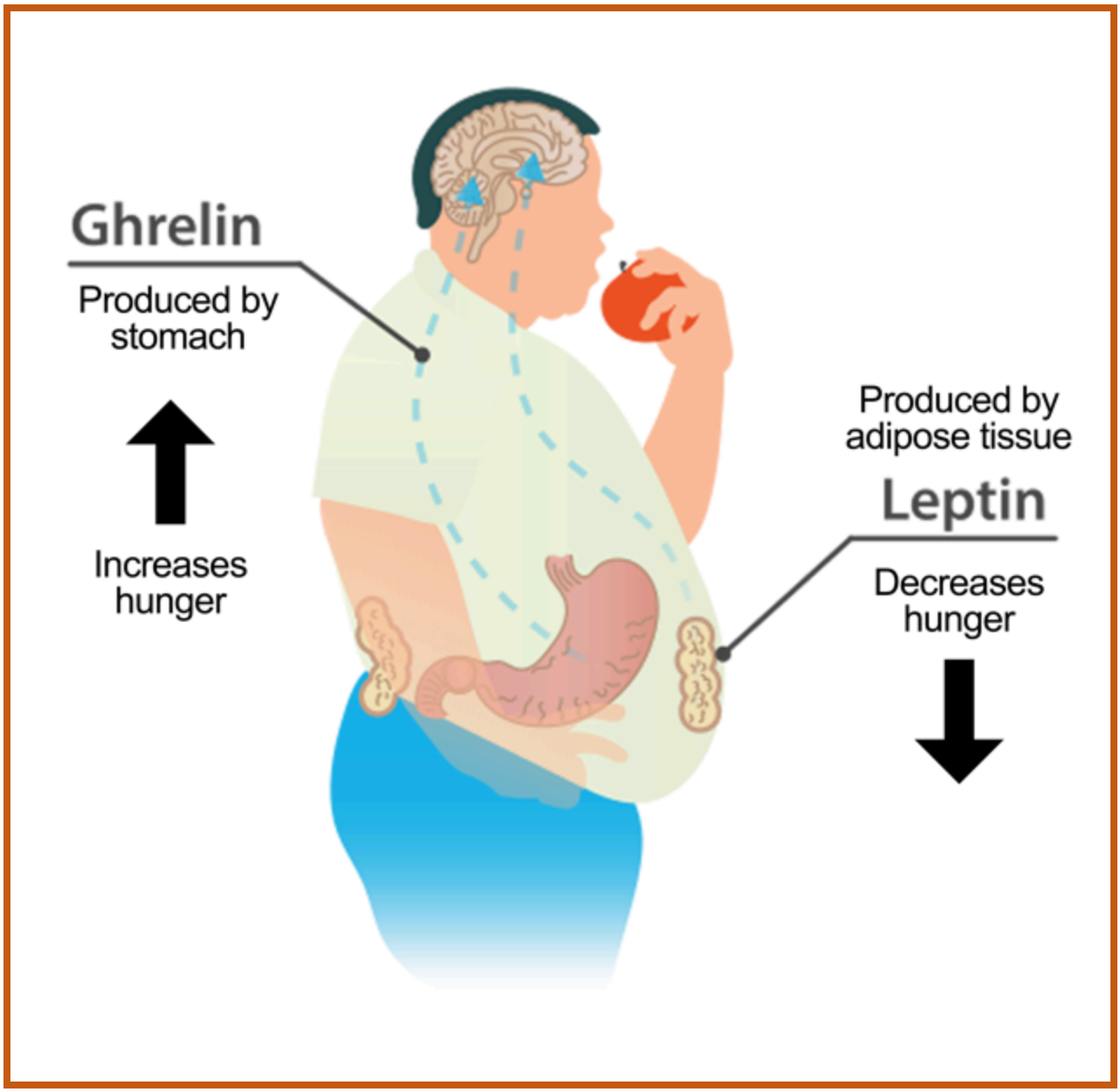


Figure 11.13: Image by InjuryMap on Wikimedia Commons. This file is licensed under CC BY-SA 4.0.

- *In individuals with obesity, leptin resistance may occur, where the brain does not properly respond to the hormone's signals, leading to a continued feeling of hunger despite having high leptin levels.*

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12

Chapter 12: Promoting Healthy Weight

12.1

Achieving a Healthy Weight

12.1 Achieving a Healthy Weight



Figure 12.1:Tools of healthy weight loss include diet, exercise, and more. Image by Fort Carson Weight Management Program on picryl.

For many, achieving and maintain a healthy weight may require changes in a person's daily habits and lifestyle, including decreasing calories consumed through food and beverages and increasing calories expended through physical activity and exercise.

Recommendations

While the recommendation to have a healthy weight to minimize health risks applies to all, not everyone needs to lose weight. Weight loss is recommended when health risks are increased due to an individual's weight. Health risks increase with a BMI greater than or equal to 30 kg/m^2 or being overweight (BMI of 25-29.9 kg/m^2) with two or more risk factors.[1] Risk factors include high blood pressure, high blood cholesterol, high triglycerides, high blood sugar, family history of heart disease, or physical inactivity.[1] In each of these circumstances, health professionals recommend weight loss.

Weight loss is recommended when:

- A person's BMI is greater than or equal to 30 kg/m^2
- Or if a person is overweight with two or more risk factors

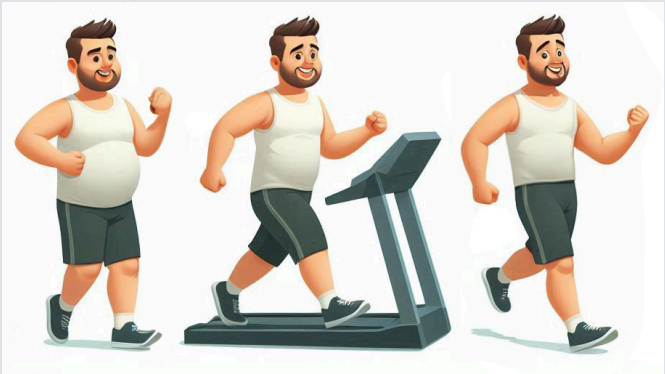


Figure 12.2 : Exercise improves weight loss. Image by AL.

In overweight and obese persons, weight loss of 5% to 10% of their body weight is recommended to reduce risk factors of chronic disease such as a reduction in triglyceride levels, lipoprotein blood cholesterol levels, blood pressure, blood glucose levels, and the development of type 2 diabetes.[2] Healthy weight loss should be gradual and steady. People who experience and maintain successful weight loss make ongoing lifestyle changes regarding diet and physical activity. The recommended rate of weight loss is up to 2 pounds per week. [3]

Recommended weight loss: up to 2 lbs per week- Modify this like the call out below

To achieve this goal, calories expended should be greater than calories consumed in food and beverages. One pound of adipose tissue provides 3500 Calories. In order to lose one pound of adipose tissue per week, a person would need to expend 500 more Calories per day than were consumed.[3]

Weight loss Example: Jane's daily caloric need is 2200 Calories. She reduced her Calorie intake by 500 calories and is consuming 1700 Calories per day. (2200-500 = 1700.) She did this for 14 days, which created a deficit of 7000 Calories. (500 x 14 = 7000.) Since there are 3500 Calories in a pound of adipose tissue, in theory, she would lose 2 pounds over that period of time. (7000/3500 = 2.)

Dieting

Many diet and exercise plans claim to help people lose large amounts of weight very quickly. Seeking quick results can lead to patterns of weight cycling, also known as yo-yo dieting.[4] Weight cycling happens when an individual makes short-term changes to lose weight. After losing weight, the individual often returns to their previous food and activity habits, causing them to regain the weight. Over the years, a person may gain and lose the same 10, 20, or even 30 pounds over and over again. Often, weight cycling eventually results in the person weighing more than before they began to diet. This weight cycling can be frustrating and discouraging and usually occurs as a result of making temporary changes in diet and exercise rather than permanent lifestyle changes.[4]

To prevent weight cycling, avoid fad diets, which gain popularity due to their claims of quick, easy weight loss.[4] Fad diets often promote rapid weight loss, no need to exercise, strict meal plans, or extreme restriction of certain foods.[4] These types of diets are often very difficult to follow long term and the weight loss is often quickly regained. Very low-calorie diets (800 Calories or less per day) are often popular because they can contribute to rapid weight loss.[5] It is difficult to meet nutrient needs when caloric intake is less than 1200 Calories per day. Very low-calorie diets and dramatic changes in weight are often associated with loss of muscle mass, a slowing of basal metabolism, and increased risk of gallstones.[4,5]

Diets that contribute to successful long-term weight loss focus on eating a variety of natural, unprocessed foods, limiting added sugar and processed foods, and appropriate portion sizes. [4]

For those trying to lose weight, a good place to start is to identify specific eating behaviors that



Figure 12.3: Dieting should include healthy foods. Image by fauxels on Pexels.

may contribute to weight gain. These may include: eating foods high in added sugars and unhealthy fats; skipping meals; eating fast food, pre-prepared foods or restaurant foods; eating mostly refined grains; snacking when not hungry; drinking

beverages with added sugars; emotional eating, or distracted eating. [6]

Making small changes in diet, which are focused on meeting the body's nutrient needs, can lead to changes that will contribute to a lifelong healthy weight. [4]

Physical Activity Guidelines



Figure 12.4: Zumba class. Image by Andrea Piacquadio on Pexels.

Control of energy intake is central to achieving and maintaining a healthy weight. Including physical activity as a part of weight control program can enhance weight loss efforts and increase health benefits. [7] The American College of Sports Medicine recommends a person participate in 150-250 minutes of moderate-intense physical activity per week to prevent weight gain or promote modest weight loss and gain substantial health benefits. [7] This can be achieved by participating in 30 minutes of moderate activity 5 days a week. Examples of moderate activity include brisk walking, biking on level terrain or swimming. [8] Greater than 250 minutes of exercise per week may result in increased weight loss and increased health benefits. The American College of Sports Medicine recommends including resistance training at least twice a week to increase muscle mass and promote the loss of fat.

Healthy Weight Gain

There are many reasons a person may have a low body weight. A low body weight may be associated with a medical condition, use of medications that impact food intake, psychological issues associated with food intake, personal genetics, a lack of food availability or a variety of other reasons[9] . Once adequate food is available and any medical barriers to food intake are removed or managed, gaining weight in a healthy manner can be addressed.

The principles for weight gain are similar to those outlined for weight loss. A modest increase in calories over the level needed to maintain weight will induce a gradual weight gain in most people. A gradual weight gain of 0.5-1.5 pounds per week is generally recommended for health. An increased calorie intake can be achieved by increasing the frequency of meals or snacks and/or increasing the caloric density of foods selected. Some tips for promoting weight gain are included in the Table 1. If physically possible, include exercise; resistance exercise will especially help promote muscle weight gain[10] .

Strategy	Examples
Including good fats to increase the caloric density of foods	• Adding avocado to a sandwich or shake • Adding flax or chia seeds to a smoothie • Adding nut butter spreads • Garnish salads with olive oil, olives, nuts, seeds or avocados
Top your foods with sources of concentrated calories	• Add cheese to the top of your chili, or to your cooked vegetables or scrambled eggs
Make your liquids count	• Drink your fluids before or after meals to leave more room for food • Drink healthy fluids, such as 100% fruit juice, that have calories as opposed to calorie free options
Boost up cereals	• Prepare oatmeal or other hot cereals with milk instead of water. Mix in dried fruits, powdered milk, honey, buts or nut butters.
Food selection	• Avoid lite or low calorie options of foods. Choose full fat options

Table 12.1: Tips for adding calories to meals[10]

In situations where war, economic issues, weather extremes or other factors cause a scarcity of food leading to severe acute weight loss and malnourishment, a variety of ready to use therapeutic foods (RUTF's) are available. Aid agencies such as the World Food Program and UNICEF utilize these products when providing emergency aid. One of the most widely used RUTF products is called Plumpy'nut. It is a shelf stable paste made of peanut butter fortified with protein and other added nutrients. It is most often used to help malnourished children. Feeding someone in this type of situation has to be done with care. In cases of extreme malnourishment, feeding too aggressively can actually be deadly. The rush of food into the system can cause shifts in already strained blood electrolyte levels leading to cardiac arrest. This is termed "Refeeding Syndrome."[1]

International Agencies that Provide Food Assistance	Food Assistant Programs in the U.S.
World Food Program	Supplemental Nutrition Assistant Program(SNAP)
Actions Against Hunger	School Meals
Care	Women Infants and Children (WIC)
United Nations Children's Emergency Fund (UNICEF)	Food banks
USAID	Meals on Wheels
Catholic Relief services	Child and Adult Care Feeding Program

International Agencies that Provide Food Assistance	Food Assistant Programs in the U.S.
LDS Charities	LDS Bishop's Store House
Bountiful Children's Foundation	

Table 12.2: Examples of agencies and programs that provide nutrition assistance

Highlight: Refeeding syndrome



One of the earliest reports of refeeding syndrome was during WWII. Prisoners of war were often starved. During the refeeding process cases of refeeding syndrome were observed and reported.[1] This led to Ansel Keys work in the Minnesota semistarvation experiment. A particularly severe case was recorded in Clare Oliphant Jr.'s autobiography of his experience in a German prisoner of war camp. The account is paraphrased below.[2]

Clare was taken as a prisoner of war by Germany on Christmas Eve of 1944. The prisoners in his camp were fed portions of watery barley soup often with carrots and potatoes and, on the rare occasion, a few pieces of meat. They were also given a piece of dense "black" bread as they called it. During February of 1945, their food rations were cut, and many prisoners were very hungry and lost a lot of weight. Clare and his fellow captives were later freed in May of 1945. It was rumored that the reason they were all so hungry in February was because Adolf Hitler had ordered the execution of all prisoners of war. The commanders of Clare's camp had apparently modified the order and instead cut their food rations including the parcels that came from the American Red Cross. On the day they were released, these parcels were found and distributed to the prisoners. One soldier prepared a five-pound cake from his share and ate it all in one sitting. He died shortly thereafter. While refeeding syndrome could not be clearly documented, the circumstances would indicate that it is a likely possibility.

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Key Takeaways

- *A healthy rate of weight loss is gradual and steady, with a recommended goal of losing up to 2 pounds per week by creating a consistent caloric deficit.*
- *To achieve successful and sustainable weight loss, it's crucial to make permanent lifestyle changes rather than relying on short-term "fad diets" or engaging in "yo-yo dieting," which can harm metabolism and often lead to weight regain.*
- *Weight loss should be a combined effort of both reducing caloric intake and increasing physical activity, with a recommendation of 150-250 minutes of moderate-intensity exercise per week.*
- *For individuals who need to gain weight, the principle is similar to weight loss: a gradual and modest increase in calories through more frequent meals and calorically dense foods, along with resistances exercise to promote muscle gain.*

- *In cases of severe malnourishment, a person must be fed with extreme caution to avoid refeeding syndrome, a potentially fatal condition caused by a rapid shift in electrolytes that can lead to cardiac arrest.*

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12.2

Behavior Modification

12.2 Behavior Modification

The ABCs of Behavior Modification



Figure 12.5: ABCs of behavior modification

In order to achieve a healthy weight, lifestyle changes are required. When it comes to daily habits, such as eating and exercise, change can be difficult. Even though this change is hard, it is not impossible. Changes toward a healthy lifestyle take place over time. There are strategies and theories that can help make behavior change successful. Successful behavior change is rarely as simple as starting or stopping something new. It requires understanding what leads to or motivates the behavior. One model that can assist in behavior change is called **the ABCs of Behavior modification**. [12] This model considers the cause and effect of a specific behavior. A is for **antecedent**, which is the action that comes before a behavior. B is for **behavior**, which is the action or habit to be changed. C is for **consequence**, which is the result of the action or behavior if it remains unchanged.[12] Sometimes understanding the consequences of a behavior can be motivation to change; however, it is often the antecedent of the behavior that must be changed. For example, Miguel has early classes and usually wakes up just in time to get to school. He realizes that he always misses breakfast. During class, Miguel gets distracted by his feelings of hunger. The antecedent in this situation is sleeping in. The behavior is missing breakfast. And the consequence is feeling hungry and distracted during class. Miguel decides to get up earlier in the mornings, changing the antecedent and then changing the behavior. When Miguel gets up earlier, he has time to eat breakfast and is more focused throughout his classes.



Figure 12.6: The ABCs of behavior modification.[12] Image by AL.

Effective Weight Loss

> "You'll never change your life until you change something you do daily. The secret of your success is found in your daily routine."
>
> - John C. Maxwell[10]

Achieving a healthy weight involves making changes regarding the mind, the body, and the stomach.[4] Achieving a healthy weight requires lasting changes to mindset, physical activity, and eating habits. The true test of an effective weight loss plan is whether a healthy weight change can be maintained over time.

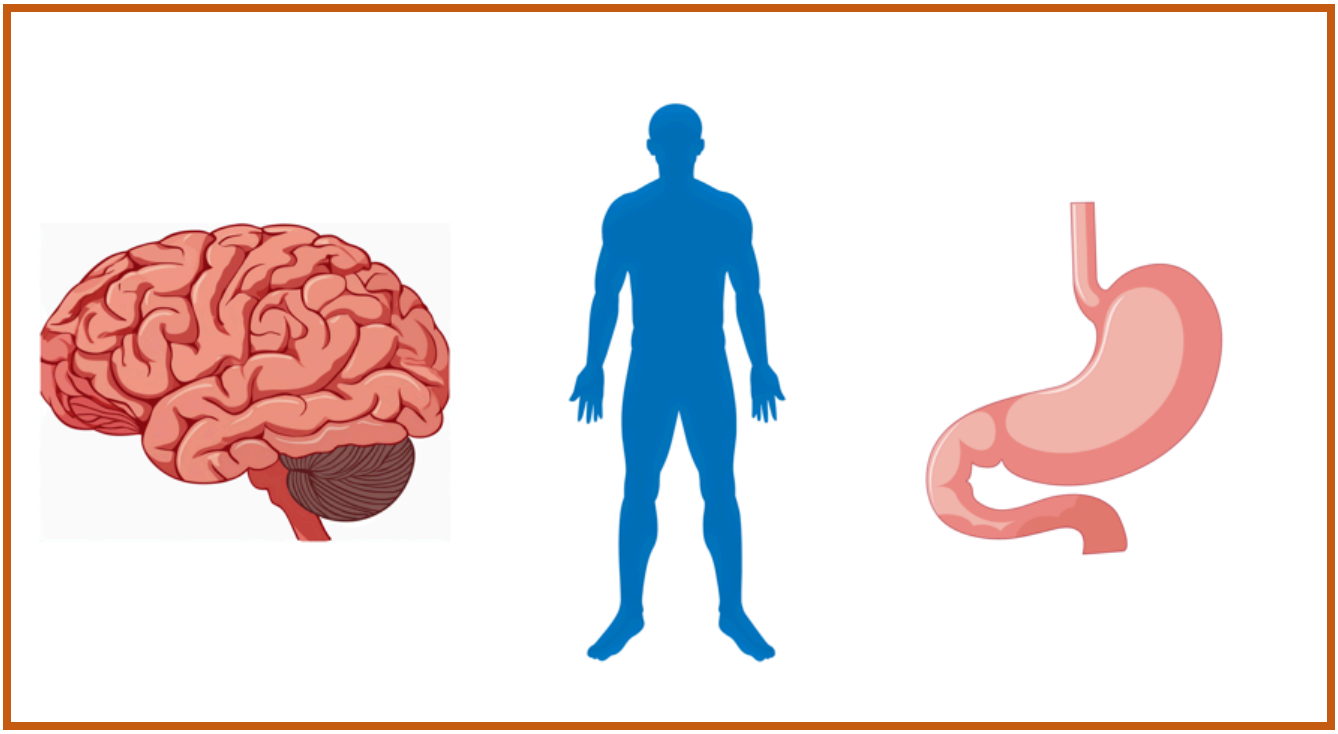


Figure 12.7: Weight loss involves the brain, body, and appetites. Image by brgfx on freepik.

Successful weight loss requires realistic expectations. By setting small, achievable goals, individuals can develop a healthy lifestyle. Rather than focusing on weight, improved health should be the central goal of any weight loss plan.[4] Focusing on long-term health, not just the number on the scale, is key to sustainable success.

Next, an individual who desires weight loss should strive to live an active lifestyle. A physically active lifestyle can contribute to heart health, bone strength, and even stress management.[4] Regular movement also improves mood, strengthens the heart and bones, and helps manage stress.

Finally, making healthy food choices is essential for sustaining a healthy weight loss. Making consistent, balanced food choices is essential for sustainable progress. The Dietary Guidelines for Americans 2020 recommends eating more vegetables, fruits, whole grains, low-fat dairy, and lean protein and consuming less saturated and trans-fats, added sugars, and sodium.[14]

12.3 Treatment for Obesity and Underweight

Medication

For some individuals, changing lifestyle habits, eating healthier, and increased physical activity may not be enough to help them lose weight long term.
For some people, lifestyle changes alone may not lead to sufficient weight loss. If this is the case, a doctor may prescribe medication or further treatment as part of a weight management program. These treatments are not recommended for everyone.
A doctor is likely to prescribe weight loss treatments involving the brain, body, and appetite.

Weight loss treatments work through the brain, body, and appetite.
"You'll never change your life until you change something you do daily. The secret of your success is found in your daily

routine." -John C. Maxwell

A doctor may prescribe weight loss medications to an adult with a BMI equal to or greater than 30 kg/m² or a BMI equal to or greater than 27 kg/m² with weight-related health problems, such as type 2 diabetes or high blood pressure. Prescription weight-loss medications work in different ways. Some medications work in the brain to decrease appetite or increase feelings of fullness. Others block the absorption of nutrients like fat. Common side effects may include dizziness, change of taste, insomnia, constipation, or dry mouth.

Orlistat, also known as Xenical or Alli, acts to block some of the dietary fat from. **Orlistat reduces the amount of dietary fat absorbed in the intestine.**
Some common adverse effects of Orlistat include decreased absorption of fat-soluble vitamins and fat excretion in stool, especially with a high-fat diet.

Weight loss medications should be used in combination with lifestyle changes, such as a reduced calorie diet and increased exercise. They work best when paired with healthy habits. A major disadvantage of drug treatment to promote weight loss is that weight regain often occurs when the medication is stopped.

GLP-1 Receptor Agonists (GLP-1s)

In recent years, a new class of medications called GLP-1 receptor agonists has become more common in weight loss treatment. These include drugs such as semaglutide (brand names: Wegovy, Ozempic) and tirzepatide (brand name: Zepbound). Originally used to treat type 2 diabetes, they are now FDA-approved for chronic weight management in adults with obesity or overweight and related conditions.

GLP-1 medications mimic a hormone naturally made in the body that helps regulate appetite and blood sugar. They slow stomach emptying and signal the brain to feel full sooner, which can lead to reduced calorie intake and significant weight loss over time.

Common side effects include nausea, vomiting, diarrhea, and constipation. In rare cases, more serious risks such as pancreatitis may occur. These medications are typically given as a once-weekly injection and must be prescribed by a healthcare provider.

Like other weight loss medications, GLP-1s should be used together with a healthy diet, regular physical activity, and behavior change strategies.[15]

Supplements

There are also some dietary supplements that are believed to promote weight loss. These supplements are often sold with unproven marketing claims of fat burning or appetite suppression.
While these supplements may contribute to short term changes in weight, they may also cause dangerous side effects and are not effective for long-term weight change.

Guarana, also known as Brazilian cocoa, is marketed as a weight loss supplement and is claimed to aid in weight loss. However, evidence shows that the caffeine content of guarana may cause side effects, such as increased heart rate and abnormal heart rhythms, that are similar to side effects seen in banned supplements. Guarana is often found in energy drinks.

Green tea and green tea extract are sometimes used to promote weight loss, but there is no evidence to support that it contributes to weight loss or maintenance of weight loss. Because of the high caffeine content, green tea can cause poor

sleep and headaches. In high concentrations, green tea has also been found to cause liver problems. For many supplements, research does not support their safety or effectiveness for lasting weight loss.

Key Takeaways

ABC model helps identify and change weight-related habits.

Change triggers (antecedents) to support better behaviors.

Focus on daily routines, not quick fixes, for lasting weight loss.

Medications can help but must be paired with lifestyle changes.

GLP-1 drugs reduce appetite but may cause side effects.

Most supplements are ineffective and may be risky.

Key Takeaways

- *To successfully change habits for weight management, you can use the ABCs of Behavior Modification model. This involves identifying the Antecedent (the trigger), the Behavior you want to change, and the Consequences of that behavior.*
- *Sustainable weight loss requires consistent, long-term changes to your daily routine rather than relying on short-term "fad diets" that often lead to a cycle of weight loss and regain.*
- *For some individuals, a doctor may prescribe weight-loss medications, such as GLP-1s, which work by slowing digestion and signaling the brain to feel full sooner. However, these medications are most effective when paired with lifestyle changes and may have side effects.*
- *Many weight-loss supplements are not supported by scientific evidence and may be ineffective or even dangerous, with potential side affects ranging from headaches to liver problems.*
- *A major disadvantage of weight-loss medications is that weight regain often occurs when the treatment is stopped, highlighting the essential role of permanent changes to diet and exercise.*

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12.3

Treatment for Obesity and Underweight

12.3 Treatment for Obesity and Underweight

Medication

For some individuals, changing lifestyle habits, eating healthier, and increased physical activity may not be enough to help them lose weight long term. If this is the case, a doctor may prescribe medication or further treatment as part of a weight management program. These treatments are not recommended for everyone. A doctor is more likely to prescribe weight loss medications to an adult with a BMI equal to or greater than 30 kg/m^2 or a BMI equal to or greater than 27 kg/m^2 with weight-related health problems, such as type 2 diabetes or high blood pressure.[15]

Prescription weight-loss medications work to treat obesity in different ways. One oral weight loss medication, phentermine, stimulates satiety in the hypothalamus resulting in suppressed appetite and decreased food intake.[15,16] Common side effects may include dizziness, change of



Figure 12.8: Weight loss medication. Image by Artem Podrez on Pexels.

taste, insomnia, constipation, or dry mouth.[2] Another medication, Orlistat, also known as Xenical or Alli, acts to block dietary fat absorption.[17] Some common adverse effects of Orlistat include decreased absorption of fat-soluble vitamins and fat excretion in stool, especially with a high-fat diet.[2] Weight loss medications should be used in combination with lifestyle changes, such as a reduced calorie diet and increased exercise.[15] A major disadvantage of drug treatment to promote weight loss is that weight regain often occurs when the medication is stopped. [15]



Figure 12.9: Green tea has several side effects and may not be effective in promoting weight loss. Image by Mareefe on Pexels.

There are also some dietary supplements that are believed to promote weight loss.[18] These supplements are often sold with unproven marketing claims of fat burning or appetite suppression. While these supplements may contribute to short term changes in weight, they may also cause dangerous side effects, and are not effective for long-term weight change.[18] Guarana, also known as Brazilian cocoa, is marketed as a weight loss supplement and is claimed to aid in weight loss. However, evidence shows that the caffeine content of guarana may cause side effects, such as increased heart rate and abnormal heart rhythms, that are similar to side effects seen in banned supplements.[18] Guarana is often found in energy drinks.[19] Green tea and green tea extract are sometimes used to promote weight loss, but there is no evidence to support that it contributes to weight loss or maintenance of weight loss.[20] Because of the high caffeine content, green tea can cause poor sleep and headaches. In high concentrations, green tea has also been found to cause liver problems.[20] For many supplements, such as guarana and green tea, research does not support the claim that they are effective in promoting weight loss.[18]

Weight-Loss Surgery

When efforts for weight loss have been unsuccessful with diet and exercise, weight loss surgery may be beneficial for individuals with extreme obesity, defined as a BMI greater than or equal to 40 kg/m^2 , or individuals with a BMI of 35 kg/m^2 with obesity-related health problems such as type 2 diabetes, heart disease, and sleep apnea.[2, 21] Possible benefits of weight loss surgery include improvements of these obesity-related health problems. Weight loss surgery may allow some individuals greater physical function and improved quality of life.[21]

Roux-en-Y gastric bypass, more commonly known as **gastric bypass surgery**, involves permanently changing the pathway of food through the digestive system (see Figure 2).2 In this procedure, the top of the stomach is stapled to create a small pouch. Then, the small intestine is cut between the duodenum and jejunum and reattached to the small pouch. The bypassed section of the duodenum is reattached to the lower part of the jejunum to provide passage for the gastric juice, bile, and pancreatic secretions. [21]

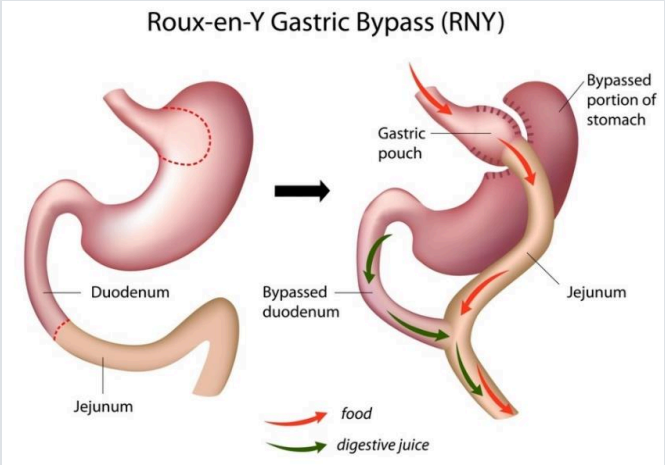


Figure 12.10: Gastric bypass surgery permanently re-routs the pathway of food. Image by Eslam ibrahim66 on Wikimedia Commons with edits by AL. This file is licensed under the CC BY-SA 4.0 license.

This smaller stomach helps people experience feelings of fullness, causing them to eat less. Gastric bypass surgery typically results in a 35% weight loss over 1 to 2 years and a 30% weight loss maintained over 10 years.[21] Common complications of weight loss surgery include bleeding, infection, leaking at the surgical site, diarrhea, blood clots, or nutrient deficiencies. [21]

Weight loss surgery does not eliminate the need for lifestyle changes. Healthy habits are necessary for long term success.[21] With the help of weight loss surgery, eating less and being more physically active may be easier. For long-term health improvements, individuals considering weight loss surgery should be ready to commit to healthy lifestyle habits for the rest of their life.[21]

Potential Complications of Weight Loss Surgery [21, 32]:

- Bleeding
- Infection
- Leaking at surgical site
- Diarrhea
- Blood clots
- Nutrient deficiencies

Treatment of Underweight

Because there are so many factors that can contribute to increased caloric expenditure or low food intake leading to a low body weight, the best way to manage a low body weight varies and often may require special medical or nutritional intervention. For example, some forms of cancer may result in an increased caloric need. Additionally, the chemotherapy treatment of some cancers results in nausea and mouth sores that make eating very difficult. The result of the increased caloric need and decreased ability to eat food can result in extreme weight loss. Medical teams may use appetite stimulants or other nutrition strategies (tube feedings, medications to manage mouth pain and nausea, or intravenous nutrition) to address this weight loss. However, the health care team must also carefully track labs and symptoms to monitor for refeeding syndrome. Even if the person is capable of eating adequate calories, their body may not be ready for it. Refeeding

can be successfully managed with careful tracking and electrolyte replacement. In cases such as anorexia nervosa, medical support may also be needed to help physical recovery, but psychological counseling should be a central factor in the treatment plan as well.

In regions where food is lacking due to weather extremes or economic issues, emergency aid can be provided, including immediate food and financial assistance. Long term solutions to provide food security also need to be addressed. For example, lack of roads and technology in some areas makes transportation of food from the farm to the market difficult and can contribute to large amounts of food waste. Improved infrastructure and food preservation techniques help the people in these areas become more self sufficient.

Key Takeaways

- *Prescription medications can be a treatment option for individuals with high BMIs and related health problems. These drugs work in different ways, either by suppressing appetite or by blocking the absorption of dietary fat.*
- *A major limitation of weight-loss medication is that they are most effective when combined with lifestyle changes, and weight regain often occurs once the medication is discontinued.*
- *Weight-loss surgery, such as gastric bypass, is a more aggressive and permanent treatment option for individuals with extreme obesity. This procedure alters the digestive system to reduce food intake, but it still requires a lifelong commitment to healthy habits for lasting success.*
- *Many over-the-counter weight-loss supplements are not supported by scientific evidence and can pose health risks. The text warns that their claims of "fat burning" or "appetite suppression" are often unproven and that some ingredients, like caffeine, can have dangerous side effects.*
- *The treatment for being underweight varies depending on the cause, such as illness or lack of food. For severely malnourished individuals, feeding must be done carefully to prevent a potentially fatal condition called refeeding syndrome.*

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12.4

Promoting Healthy Weights during the Lifecycle

12.4 Promoting Healthy Weights during the Lifecycle

Weight Gain during Pregnancy

During pregnancy, a mother's body changes in many ways. One of the most notable and significant changes is weight gain. BMI can be used to determine body size. A woman's pre-pregnancy BMI can be used to determine a healthy amount of weight to gain during pregnancy (see Table 3). Poor weight gain, especially in the third trimester, could result not only in low birth weight but also infant mortality and intellectual disabilities. The mother may also deliver a preterm baby (born before 36 weeks gestation). Preterm babies are usually born small and are at risk for other concerns such as difficulty breathing, difficulty eating and difficulty maintaining their body temperature

Pre-pregnancy BMI	Weight Category	Recommended Weight Gain
Below 18.5	Underweight	28 - 40 lbs.
18.5 - 24.9	Normal	25 - 35 lbs.
25.0 - 29.9	Overweight	15 - 25 lbs.
Above 30.0	Obese	11 - 20 lbs.

Table 12.3: Weight Gain Recommendations for Pregnancy[22]

Starting weight below or above the normal range can lead to different complications. Pregnant women with a pre-pregnancy BMI below twenty are at higher risk of a preterm delivery and an underweight infant. Pregnant women with a pre-pregnancy BMI above thirty have an increased risk of the need for a cesarean section during delivery. Therefore, it is optimal to have a BMI in the normal range prior to pregnancy.

Generally, women gain 2 to 5 pounds in the first trimester. After that, it is recommended to gain approximately one pound per week during the second and third trimesters. Some of the new weight is due to the growth of the fetus, while some is due to changes in the mother's body that support the pregnancy. Weight gain often breaks down in the following manner (see Figure 3):

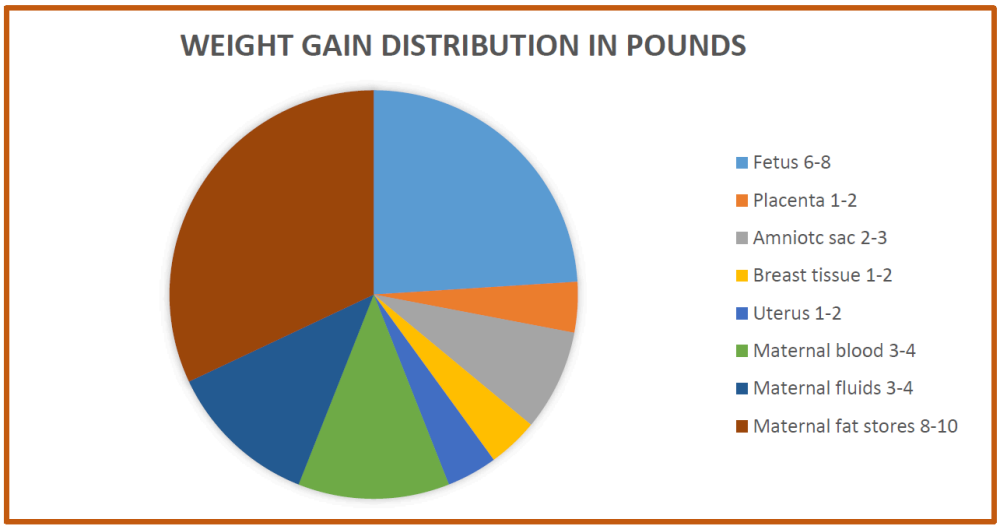


Figure 12.4: Distribution of recommended weight gain during pregnancy[22]

Women who are pregnant with more than one fetus are advised to gain even more weight to ensure the health of their unborn babies.

The pace of weight gain is also important. If a woman puts on weight too slowly, her physician may recommend nutrition counseling because inadequate weight gain can increase the risk of delivering a baby early or having a baby that does not have sufficient stores. If she gains weight too quickly, especially in the third trimester, it may be the result of edema, or swelling due to excess fluid accumulation. Rapid weight gain may also result from increased calorie consumption or a lack of exercise. A baby's birthweight can help assess how well the pregnancy went. An infant's weight can be categorized as **Small for Gestational Age** (SGA), **Average for Gestational Age** (AGA) or **Large for Gestational Age** (LGA).

Category	Weight Range
SGA	Weight below the 10th percentile
AGA	Weight between the 10th and 90th percentile
LGA	Weight above the 90th percentile

Table 12.5: Birthweight Categories[23] *Assessing Growth in Infants*

Healthy infants grow steadily but not always at an even pace. For example, during the first year of life, length increases by 50 percent, while weight triples. Physicians and other health professionals can use growth charts to track a baby's development

process. Because infants cannot stand, the length is used instead of height to determine the rate of a child's growth. Other important developmental measurements include head circumference and weight. All of these must be tracked and compared against standard measurements for an infant's age. Nationallyaccepted growth charts are based on data collected by the National Center for Health Statistics. [24] These charts allow for tracking trends over time and comparing with other infants among percentiles within the United States. Growth charts may provide warnings that a child has a medical problem or is malnourished. Insufficient weight or length gain during infancy may indicate a condition known as failure-to-thrive (FTT), which is characterized by poor growth. FTT can happen at any age, but in infancy, it typically occurs after six months. Some causes include poverty, lack of enough food, feeding inappropriate foods, and excessive intake of fruit juice.

Measuring and tracking an infant's growth is one of the best ways to monitor if the child is receiving adequate nutrition. Common measurements during the first year of life are length-forage, weight-for-age, length-for-weight and head circumference-for-age. To best identify proper growth, it is best to plot these measurements on a growth chart. For infants, the charts that are recommended to use are the World Health Organization (WHO) growth charts. These charts were developed using infants that were exclusively breastfed for at least 4 months. The percentiles in the WHO growth charts better reflect the pattern set by following recommendations regarding breastfeeding. The Centers for Disease Control (CDC) charts were developed tracking the growth of infants that were not necessarily breastfed for the recommended amount of time. It is recommended to use the WHO growth charts until the age of two.[24] Percentiles reflect how children grow compared to children of the same age and gender. For example, a 3-month-old baby girl plotted at the 30th percentile indicates that out of 100 3-month-old baby girls, 30 would be smaller and 70 would be larger. The goal is to have a child follow their growth curve or percentile. If a drastic change is noted in the growth pattern over time it can be an indication of problems. For example, if an infant born at the 30 percentile stays consistent on the growth chart until 6 months, but then from 6-9 month drops from the 30th, then to the 10th and then below the 5th percentile, the change that occurred between months 6 and 9 is concerning. It would also be a concern if that child's weight went from the 30th, then to the 60th and then the 90th percentile in the same period. Without using growth charts, two "checkpoints" can be monitored to do a less detailed assessment of weight and nutritional status. Normal growth would be indicated by the baby's weight doubling by about 5 months and tripling by one year of age. [25]



Figure 12.11: Family exercise is a good way to promote healthy weights and lifestyles to children. Image by RDNE Stock project on Pexels.

Healthy Weights in Childhood

The percentage of children with obesity in the United States has more than tripled since the 1970's.[26] There are several contributing factors for the increase in obesity in children. Some factors that may contribute include:[27-29]

- Genetics
- Metabolism—how your body changes food and oxygen into the energy it can use

- Eating and physical activity behaviors
- Environmental factors
- Social and individual psychology

There are recommendations regarding both food intake and physical activity to help promote healthy weights and lifestyles in children. It is very effective to teach children to eat healthily and be active by example. Incorporating activity into daily life is a good way to increase movement throughout the day to help build good habits. The diet and activity recommendations are summarized in Table 5.

Dietary Modifications	Physical Activity Recommendations
Eat more fresh fruits and vegetables	At least 60 minutes of physical activity daily
Decrease intake of added sugars (soda, candy)	Watch less television (less screen time)
Decrease intake of solid fats	Parents encourage games, walks, hikes together
Eat meals at a table instead of in front of TV	
Parents provide appropriate portion sizes	

Table 12.5: Diet and activity recommendations to promote healthy weights in children[30]

Research on the topic of childhood obesity has revealed relationships with immediate effects on their health, not only physical but emotional and social health as well. Children with obesity are impacted in the following ways (see Table 6):

Physical Health	Emotional Health	Social Health
Asthma Sleep apnea Bone And joint pain Type 2 diabetes Risk factors for heart disease	Depression Low self-esteem	Bullied and teased more often than healthy weight peers Social isolation

Table 12.6: Immediate effects of obesity on children's health[31]

In addition to immediate effects, children with obesity also have higher risk factors for diseases as adults such as obesity, Type 2 diabetes, heart disease, metabolic syndrome, and several types of cancer.

Key Takeaways

- *As healthy weight gain during pregnancy is crucial for both the mother's and the baby's health. The recommended amount of weight gain is determined by the mother's pre-pregnancy BMI, as both too little and too much gain can lead to complications.*
- *An infant's healthy growth is best assessed by tracking measurements like weight and length on growth charts. A significant or sudden change in a child's growth pattern can be a warning sign of a nutritional or medical issue, such as failure-to-thrive (FTT).*

- *The percentage of children with obesity has more than tripled since the 1970s. This is a complex issue influenced by genetics, metabolism, and environmental factors such as eating and physical activity behaviors.*
- *Childhood obesity has immediate negative effects on a child's physical health, increasing the risk for conditions like asthma and type 2 diabetes, as well as emotional and social issues like depression and social isolation.*
- *Promoting healthy weights in children is most effective through a combination of balanced dietary choices (e.g., more fruits and vegetables, less added sugar) and at least 60 minutes of daily physical activity. Parents can play a key role by setting a positive example.*

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13

Chapter 13: Life Cycle

13.1

Nutrition and Pregnancy

13.1 Nutrition and Pregnancy

Introduction

Human bodies change significantly over time, and food is the fuel for those changes. People of all ages need the same basic nutrients—essential amino acids, carbohydrates, essential fatty acids, and twenty-eight vitamins and minerals—to sustain life and health. However, the amounts of nutrients needed differ. Throughout the human life cycle, the body constantly changes and goes through different periods known as stages. One stage that requires different nutrient needs is pregnancy.



Figure 13.1:Healthy habits during pregnancy will help the health of the unborn child. Image by cottonbro studio on Pexels.

For medical purposes, **pregnancy** is measured from the first day of a woman's last menstrual period until childbirth, and typically lasts about forty weeks. These forty weeks are then broken down into trimesters which are approximately 13 weeks each. Major changes begin to occur in the earliest days of pregnancy, often weeks before a woman even knows she is pregnant. During this period, adequate nutrition supports cell division, tissue differentiation, and organ development. As each week passes, new milestones are reached. Therefore, women who are trying to conceive should make proper dietary choices

to ensure the delivery of a healthy baby. Fathers-to-be should also consider their eating habits. A sedentary lifestyle and a diet low in fresh fruits and vegetables may affect male fertility. Men who drink too much alcohol may also damage the quantity and quality of their sperm. [1] For both men and women, adopting healthy habits also boosts general well-being and makes it possible to meet the demands of parenting.

During pregnancy, a **placenta** is also developed in the uterus. The placenta plays a critical role during pregnancy in the nutrition of the fetus. Its role is to deliver nutrients and oxygen to the baby and remove waste products from the baby's blood.

Knowing that nutrition during pregnancy is so vital, The Church of Jesus Christ has even published a statement in *The Latter-Day Saint Woman* which says, "It is important that a pregnant woman eat a healthful variety of foods. Eating properly has a great influence on the unborn baby. Eating well is so important that all potential mothers need to prepare their bodies by carefully choosing what they eat. When they do so, they will have a better chance of having good health and bearing healthy children. When a young woman makes a habit of eating a variety of healthful foods in sufficient amounts, her ability to give birth to healthy children is improved. Because these established good eating habits will go with her into marriage and pregnancy, she will continue eating the right foods and teach the same good habits of nutrition to her children."[2]

Discomforts and Complications of Pregnancy

Pregnancy can lead to certain discomforts, from back strain to swollen ankles. Pregnant women are also likely to experience constipation because increased hormone levels can slow digestion and relax muscles in the bowels. Constipation and pressure from growth of the uterus can result in hemorrhoids, which are another common discomfort.[3] Getting mild to moderate exercise and drinking enough fluids can help prevent both conditions. Also, eating a high-fiber diet softens the stools and reduces the pressure on hemorrhoids.

Heartburn can occur during the early months of pregnancy due to an increase in the hormone progesterone, and during the later months due to the expanding size of the fetus, which limits



Figure 13.2 :Pregnant woman suffering from nausea. Image by AL.

stomach contraction. Avoiding chocolate, mint, and greasy foods, and remaining upright for three hours after meals can help pregnant women avoid heartburn. In addition, it can be helpful to drink fluids between meals, instead of with food.

Other common complaints can include leg cramps and bloating. Regular exercise can help to alleviate these discomforts. A majority of pregnant women develop gastrointestinal issues, such as nausea and vomiting. Many also experience food cravings and aversions. All of these can impact a pregnant woman's nutritional intake and it is important to protect against adverse effects.

Nausea and Vomiting

Nausea and vomiting are gastrointestinal issues that affect many pregnant women, typically in the first trimester. Nausea tends to occur more frequently than vomiting. These conditions are often referred to as "morning sickness," although that's something of a misnomer because nausea and vomiting can occur all day long, although it is often worst in the first part of the day.

Increased levels of the pregnancy hormone human chorionic gonadotropin may cause nausea and vomiting, although that is speculative. Another major suspect is estrogen because levels of this hormone also rise and remain high during pregnancy. Given that a common side effect of estrogen-containing oral contraceptives is nausea this hormone likely has a role. Nausea usually subsides after sixteen weeks, possibly because the body becomes adjusted to higher estrogen levels.

It can be useful for pregnant women to keep a food diary to discover which foods trigger nausea, so they can avoid them in the future. Other tips to help avoid or treat nausea and vomiting include the following:

- Avoid spicy foods
- Avoid strong or unusual odors
- Eat dry cereal, toast, or crackers
- Eat frequent, small meals
- Get moderate aerobic exercise
- Drink ginger ale or ginger tea, which helps aids in stomach upset
- Seek fresh air when a bout of nausea comes on

A severe form of nausea and vomiting is a condition known as

hyperemesis gravidarum
. It is marked by prolonged vomiting, which can result in dehydration and require hospitalization. This disorder is relatively rare and impacts only 0.3 to 2 percent of all pregnant women.[4]

Food Cravings and Aversions

Food aversions and cravings do not have a major impact unless food choices are extremely limited. The most common food aversions are milk, meats, pork, and liver. For most women, it is not harmful to indulge in the occasional craving, such as the desire for pickles and ice cream. However, a medical disorder known as pica is willingly consuming foods with little or no nutritive value, such as dirt, clay, and laundry starch. In some places this is a culturally accepted practice. However, it can be harmful if these substances take the place of nutritious foods or contain toxins.

Gestational Diabetes

Pregnant women who never had diabetes before and experience high blood sugar levels during pregnancy are diagnosed with **gestational diabetes**. The prevalence of gestational diabetes is estimated as high as 9.2%.[5] The body becomes resistant to the hormone insulin, which enables cells to transport glucose from the blood. Gestational diabetes is usually diagnosed

around twenty-four to twenty-six weeks, although it is possible for the condition to develop later into a pregnancy. Most women are given a test around this time of pregnancy to identify gestational diabetes. If blood sugar levels are not properly monitored and treated, the baby might gain too much weight and require a cesarean delivery. Diet and regular physical activity can help to manage this condition. Gestational diabetes usually resolves after childbirth, although some women who suffer from this condition develop Type 2 diabetes later in life, particularly if they are overweight. A previous diagnosis of gestational diabetes increases the risk of getting Type 2 Diabetes by up to 60%.[6]

Gestational Hypertension



Figure 13.3 Pregnant woman having blood pressure measured. Image by AL.

Elevated blood pressure that begins in the second half of pregnancy is referred to as gestational hypertension. Approximately 5- 8% of pregnant women worldwide experience hypertensive disorders.[7] First time mothers are at a greater risk, along with women who have mothers or sisters who had gestational hypertension, women carrying multiple fetuses, women with a prior history of high blood pressure or kidney disease, and women who are overweight or obese when they become pregnant.

Hypertension can prevent the placenta from getting enough blood, which would result in the baby getting less oxygen and nutrients. This can result in low birth weight, although most women with gestational hypertension can still deliver a healthy baby if the condition is detected and treated early. Some risk factors can be controlled, such as diet, while others cannot, such as family history. If left untreated, gestational hypertension can lead to a serious complication called preeclampsia, which is sometimes referred to as toxemia. This disorder is marked by elevated blood pressure and protein in the urine and is associated with swelling, or edema. Because this condition is so serious, it is recommended that all women regularly attend their prenatal checkups to monitor for this and overall health of the mother and baby during pregnancy.[8]

Key Takeaways

- *Adequate nutrition is critical even before conception, as a healthy diet for both parents can improve fertility and support the earliest stages of fetal development.*

- *Common discomforts of pregnancy, such as nausea, constipation, and heartburn, can often be managed through simple dietary and lifestyle changes like eating frequent, small meals and ensuring adequate fluid and fiber intake.*
- *Gestational diabetes, a condition of high blood sugar during pregnancy, can lead to the baby gaining too much weight and increases the mother's risk of developing Type 2 diabetes later in life.*
- *Gestational hypertension (elevated blood pressure during pregnancy) can restrict nutrient and oxygen delivery to the fetus. If left untreated, it can lead to preeclampsia, a serious and potentially dangerous complication for both mother and baby.*
- *The placenta is a vital organ that forms during pregnancy to deliver nutrients and oxygen to the fetus and remove waste products. Its proper function is dependent on the mother's nutritional status.*

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13.2

Nutrition Recommendations for Pregnancy

13.2 Nutrition Recommendations for Pregnancy

As a female's body changes during pregnancy, so do her nutritional needs. Pregnant women must consume more calories and nutrients in the second and third trimesters than other adult women. However, the average recommended daily caloric intake can vary depending on activity level and the mother's normal weight. Also, pregnant women should choose a high-quality, varied diet, consume fresh foods, and prepare nutrient-rich meals. Although it is possible to consume adequate nutrients with a well-balanced diet, it can be difficult; for that reason, supplementation during pregnancy is generally recommended.

Energy

During the first trimester, a pregnant woman has the same energy requirements as prior to pregnancy. However, as the pregnancy progresses, a woman needs to increase her caloric intake. According to the Centers for Disease Control and Prevention, [9] the caloric recommendation for the second trimester is to consume an additional 340 Calories per day above the caloric needs prior to pregnancy. During the third trimester the recommendation is an additional 452 Calories per day above the pre-pregnant caloric needs. The increased calories go toward the increased maternal metabolism, the baby's development, and building fat stores to support lactation after pregnancy. A woman can easily meet these increased needs by consuming more nutrient-dense foods. For example, **Table 13.1** shows food that would increase intake by about 340 Calories.

		
1 medium-sized banana	6 ounces low-fat vanilla yogurt	1 slice whole-wheat toast with 1 teaspoon jam
100 Calories	140 Calories	75 Calories (toast) 25 Calories (jam)
		Total: 340 Calories

Table 13.1: Additional calories required by pregnancy in second trimester. Images by AL.

Carbohydrates

The recommended daily allowance, or RDA, for carbohydrates during pregnancy is a minimum of 175 grams per day to fuel maternal and fetal brain development.[10] The best carbohydrate food sources for pregnant women include whole-grain breads and cereals, brown rice, root vegetables, legumes, and fruits. These and other unrefined carbohydrates provide energy, nutrients, phytochemicals, antioxidants, and fiber. These foods also help to build the placenta and supply energy for the growth of the unborn baby. Refined carbohydrates, such as white bread, cookies and other baked desserts, pretzels, and chips are still a source of carbohydrates, however, they have low nutrient density and should be eaten in moderation.

Protein



Figure 13.4 Pregnant woman with healthy snacks. Image by AL.

During pregnancy, extra protein is needed for the synthesis of new maternal and fetal tissues. Proteins build muscle and other tissues, enzymes, antibodies, and hormones in both the mother and the unborn baby. Additional protein also supports increased blood volume and the production of amniotic fluid. The RDA for protein during the second half of pregnancy (weeks

20-40) is 1.1 grams/kilogram per day based off of pre-pregnancy body weight, which is higher than the recommendation for non-pregnant women. [10] However, in most instances, there is no need for a pregnant woman to make a focused effort to increase protein intake as long as she has a normal appetite. Protein should be derived from healthy sources, such as lean red meat, white-meat poultry, legumes, nuts, seeds, eggs, and fish. Low-fat milk and other dairy products also provide protein, along with calcium and other nutrients.

Fat

There are no specific recommendations for fats during pregnancy, apart from following normal dietary guidelines. Fats should make up 20 to 35 percent of daily calories, and those calories should come from healthy fats, such as avocados, nuts and oils. It is not recommended for pregnant women to be on a very low-fat diet, since it would be hard to meet the needs of essential fatty acids and fat-soluble vitamins. Fatty acids are important during pregnancy because they support the baby's brain and eye development. In particular, the brain depends on omega3 (DHA) and omega-6 fatty acids for function, structure, and growth. Fats can also help the

placenta grow and may help to prevent premature birth and low birth weight. There are several healthy sources of dietary fat. It is recommended that women eat a variety of these sources, including fish. Coldwater fish such as salmon, and even tuna, are good sources of the omega-3 fatty acids EPA and DHA. It is recommended that pregnant women avoid shark, king mackerel, swordfish and tilefish due to the high level of mercury in these fish. Other than avoiding these fish high in mercury, it is recommended that pregnant women eat 8-12 ounces of a variety of fish per week.[11]

Fiber

The recommendation for fiber for pregnant women is 28 grams of dietary fiber per day.[10] Pregnant women should consume both soluble and insoluble fiber. Insoluble fiber helps soften stools and speeds the elimination of waste material through the colon to avoid constipation. Soluble fiber helps to lower blood-cholesterol levels and regulate blood glucose. Sources of fiber include whole grains, fruits, vegetables, dried peas, and beans.

Fluids

According to the Institutes of Medicine, pregnant women should drink 2.3 liters (about 10 cups) of liquids per day to provide enough fluid for blood production. It is also important to drink liquids during physical activity or when it is hot and humid outside, to replace fluids lost through perspiration. The combination of a high-fiber diet and lots of liquids also helps to prevent constipation.[12]

Vitamins and Minerals

Recommendations for most vitamins and minerals increase slightly during pregnancy. Most of these requirements can be fulfilled with a healthy diet. However, taking a daily prenatal supplement or multivitamin is often recommended to help meet many nutritional needs. **Table 1** (see below) shows the vitamin and mineral recommendations for non-pregnant and pregnant women

The micronutrients involved with building the skeleton—vitamin D, calcium, phosphorus, and magnesium—are crucial during pregnancy to support fetal bone development. Although the levels are the same as those for non-pregnant women, many women do not typically consume adequate amounts of these nutrients and should make an extra effort to meet those needs during pregnancy. Even though the amount of calcium absorption doubles, the intake of calcium needs to remain at the recommended level to meet the extra demands of pregnancy for this nutrient.[13]

Additional iron intake is important because of the increase in blood volume during pregnancy required to support the fetus and placenta. Iron-deficiency anemia during pregnancy has been linked to the risk of preterm delivery and low-birthweight



Figure 13.5 Sources of healthy fats. Image by AL.

infants by two to three times. It is possible this is related to the decreased oxygen supply to the fetus and placenta, increased rates of infection or adverse effects on brain development that may occur with low iron stores in the mother.[14] It is optimal to have a female enter pregnancy with adequate iron stores to better meet her needs as it is difficult to make up low iron levels and also meet the increased demands of pregnancy. Obtaining the increased recommendation for iron is very difficult for many women.

Oftentimes, even if a pregnant woman consumes a healthy diet, there still is a need to take an iron supplement.

Vitamin	Non-Pregnant Females	Pregnant Females
Vitamin A (mcg)	700	770
Vitamin B6 (mg)	1.3	1.9
Vitamin B12 (mcg)	2.4	2.6
Vitamin C (mg)	75	85
Vitamin D (mcg)	15	15
Vitamin E (mg)	15	15
Calcium (mg)	1000	1000
Folate (mcg)	400	600
Iron (mg)	18	27
Magnesium (mg)	310	350
Niacin (mg)	14	18
Phosphorus (mg)	700	700
Riboflavin (mg)	1.1	1.4
Thiamine (mg)	1.1	1.4
Zinc (mg)	8	11

Table 13.2: RDA values for vitamins and minerals of non-pregnant and pregnant females[10]

Folate needs increase during pregnancy from 400 micrograms to 600 micrograms per day to prevent neural tube defects. Neural tube defects are conditions associated with the development of the brain, spine, or spinal cord. These defects occur early in pregnancy, prior to day 28, usually before the woman even knows she is pregnant. The two most common neural tube defects are spina bifida and anencephaly.[15] These conditions vary in severity from some paralysisin the lower limbs in spina bifida to an undeveloped brain or skull (anencephaly). Babies born with anencephaly are usually either stillborn or die shortly after birth. Folate is also crucial for fetal development because it helps produce the extra blood a woman's body requires throughout pregnancy. Low folate intake is associated with fetal growth restriction, premature and low-birthweight infants. [16]

For most other micronutrients, recommended intakes are similar to those for non-pregnant women, although it is crucial for pregnant women to make sure to meet the RDAs to help with proper development. In addition, pregnant mothers should avoid exceeding any recommendations. Taking mega-doses of supplements can lead to excessive intake of certain micronutrients, such as vitamin A and zinc, which may produce toxic effects that can also result in birth defects.

Teratogens

Teratogens are substances that can be harmful to the fetus if they are present during pregnancy.[17] Examples of teratogens that may cause harm to the fetus include mercury, alcohol, marijuana, prescription and illegal drugs and harmful levels of Vitamin A. These substances may cause physical and/or mental abnormalities for the developing fetus. When alcohol is ingested by a pregnant woman, it readily passes through the placenta to the developing fetus. Negative effects of alcohol intake during pregnancy may include abnormal mental development and growth of the fetus. Therefore, it is advised that women that are or may become pregnant do not drink alcohol.[51]

Physical Activity during Pregnancy



Figure 13.6 Pregnant woman exercising. Image by Jessica Monte on Pexels.

For most pregnant women, physical activity is important and is recommended in the 2018 Physical Activity Guidelines for Americans. [18] Unless women has medical reasons to avoid physical activity during pregnancy it is recommended to have 150 minutes of regular moderate-intensity aerobic activity. This can be met with 30 minutes of activity per day most days of the week. Regular activity keeps the heart and lungs healthy and helps improve sleep, boosts mood and energy levels. In addition, women who participate in regular physical activity during pregnancy report fewer discomforts and may have an easier time losing excess weight after childbirth. Brisk walking, swimming, or an aerobics class geared toward expectant mothers are all great ways to get physical activity during pregnancy. Healthy women who already participate in vigorous activities, such as running, can continue doing so during pregnancy if they discuss an exercise plan with their physician. [19]

However, pregnant women should avoid pastimes that could cause injury, such as soccer, football, and other contact sports, or activities that could lead to falls, such as horseback riding and downhill skiing. It may be best for pregnant women not to participate in certain sports that require you to jump or change direction quickly, or laying on their back after the first trimester. Scuba diving should also be avoided because it might result in the fetus developing decompression sickness. This potentially fatal condition results from a rapid decrease in pressure when a diver ascends too quickly.

Key Takeaways

- *A pregnant woman's energy and nutrient needs increase significantly in the second and third trimesters. It is often recommended to take a daily prenatal supplement to ensure these needs are met.*
- *The micronutrient folate is crucial for preventing neural tube defects, which are birth defects of the brain and spinal chord that can occur very early in pregnancy.*

- *A pregnant woman's need for iron increases substantially due to a rise in blood volume. Iron-deficiency anemia can lead to a higher risk of preterm delivery and low-birth-weight infants, making supplementation often necessary.*
- *Teratogens—substances like alcohol, mercury, and certain drugs—can be very harmful to a developing fetus and should be completely avoided during pregnancy.*
- *Unless medically advised against it, pregnant women should engage in at least 150 minutes of moderate-intensity physical activity per week, but should avoid activities with a high risk of injury, such as contact sport*

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13.3

Lactation

13.3 Lactation



Figure 13.7 New mothers will need to decide if they will breastfeed. Image by Jonathan Borba on Pexels.

After the birth of the baby, nutritional needs must be met to ensure that an infant not only survives but thrives from infancy into childhood. Breastfeeding provides the fuel newborns need for rapid growth and development. As a result, the World Health Organization (WHO) recommends that breastfeeding be done exclusively for the first six months of an infant's life, with continued breastfeeding along with the introduction of complimentary foods for 2 years or longer. [20] New mothers must also consider their own nutritional requirements to help their bodies recover from pregnancy. This is particularly true for women who breastfeed their babies, which calls for an increased need in certain nutrients.

Lactation is the process that makes breastfeeding possible and is the synthesis and secretion of breast milk. Early in a woman's pregnancy, her mammary glands begin to prepare for milk production. Hormones play a major role in this, particularly during the second and third trimesters. At that point, levels of the hormone **prolactin** increase to stimulate the growth of the milk duct system, which initiates and maintains milk production. Levels of the hormone **oxytocin** also rise to promote the release of breast milk when the infant suckles, which is known as the milk ejection reflex, or letdown. However,

levels of the hormone progesterone need to decrease for successful milk production, because progesterone inhibits milk secretion. Shortly after birth, the expulsion of the placenta triggers progesterone levels to fall, which activates lactation.[21]

Nutrition Recommendations

New mothers need to adjust their caloric and fluid intake to make breastfeeding possible. The RDA is an additional 330 Calories from baseline caloric needs during the first six months of lactation and an additional 400 Calories from baseline caloric needs during the second six months of lactation. The energy needed to support breastfeeding comes from both increased intake and from maternal fat stores. For example, during the first six months after her baby is born, the daily caloric cost for a lactating mother is 500 Calories, with 330 Calories derived from increased intake and 170 Calories derived from maternal fat stores. This helps explain why breastfeeding may promote weight loss in new mothers. Lactating women should also drink 3.1 liters of liquids per day (about 13 cups) to maintain milk production, according to the Institutes of Medicine (IOM). As is the case during pregnancy, the RDA of nearly all vitamins and minerals increases for women who are breastfeeding their babies. The protein RDA for women who are lactating is 1.3 grams/kilogram of pre-pregnant body weight. [10]

Benefits of breastfeeding

Breastfeeding has several benefits, both for the mother and for the child. Breast milk contains immunoglobulins, enzymes, immune factors, and white blood cells. As a result, breastfeeding boosts the baby's immune system and lowers the incidence of diarrhea, along with respiratory diseases, gastrointestinal problems, and ear infections. Breastfed babies also are less likely to develop asthma and allergies. Breastfeeding lowers the risk of sudden infant death syndrome. In addition, human milk encourages the growth of healthy bacteria in an infant's intestinal tract. All of these benefits remain in place after an infant has been weaned from breast milk. Studies also report other possible long-term effects. For example, breast milk may improve an infant's intelligence and protect against Type 1 Diabetes, Type 2 Diabetes, celiac disease and obesity. [22]

Breastfeeding has several other important benefits. It is easier for babies to digest breast milk than bottle formula because it contains higher amounts of casein which is a protein that curds in the stomach.23 Breastfeeding can also save families money because it does not incur the same cost as purchasing formula. Another benefit is that breast milk is always ready. It does not have to be mixed, heated, or prepared. Also, breast milk is sterile and is always at the right temperature.

In addition, the skin-to-skin contact of breastfeeding promotes a close bond between mother and baby, which is an important emotional and psychological benefit. The practice also provides health benefits for the mother. Breastfeeding releases hormones that helps the uterus shrink back to its normal size and helps a woman's bones stay strong, which protects against fractures later in life. Studies have also shown that breastfeeding reduces the risk of type 2 diabetes and breast and ovarian cancers.[24]

Barriers to breastfeeding

Although breast milk is ideal for almost all infants, there are some challenges that nursing mothers may face when starting and continuing to breastfeed their infants. Possible obstacles may include painful engorgement or fullness in the breasts, sore and tender nipples, little support from family and peers, low levels of comfort or confidence in public, and lack of accommodation to breastfeed or express milk in the workplace.

One of the first challenges nursing mothers face is learning the correct technique. It may take a little time for a new mother to help her baby properly latch on to her breast. Improper latching can result in inadequate intake, which could slow growth and development. However, International Board Certified Lactation Consultants (IBCLCs), trained OB nurses, and trained registered dietitians are qualified to help new mothers learn the proper technique. Education, the length of maternity leave, and laws to protect public breastfeeding, among other measures, can all help to facilitate breastfeeding for many lactating women and their newborns.

Contraindications to breastfeeding

Although there are numerous benefits to breastfeeding, in some cases there are also risks that must be considered. In the developed world, a new mother with HIV should not breastfeed, because the infection can be transmitted through breast milk. These women typically have access to bottle formula that is safe, and can be used as a replacement for breast milk. However, in developing nations where HIV infection rates are high and acceptable infant formula can be difficult to come by, many newborns would be deprived of the nutrients they need to develop and grow. Also, inappropriate or contaminated bottle formulas cause 1.5 million infant deaths each year. As a result, the WHO recommends that women infected with HIV in the developing world should nurse their infants while taking antiretroviral medications to lower the risk of transmission.[25]

Breastfeeding also is not recommended for women undergoing radiation or chemotherapy treatment for cancer. Additionally, if an infant is diagnosed with **galactosemia**, meaning an inability to process the simple sugar galactose, the child must be on a galactose-free diet, which excludes breast milk. This genetic disorder is a very rare condition, however, and only affects 1 in thirty- to sixty thousand newborns.[26] When breastfeeding is contraindicated for any reason, formula enables parents and caregivers to meet their newborn's nutritional needs.

Key Takeaways

- *Lactation is a hormonal process where prolactin stimulates milk production and oxytocin promotes its release. The World Health Organization recommends exclusive breastfeeding for the first six months of an infant's life.*
- *Lactating mothers have increased nutritional needs, requiring an additional 330-400 calories and about 13 cups of fluids per day. A portion of the energy needed for milk production comes from maternal fat stores, which can help new mothers lose postpartum weight.*
- *Breastfeeding offers numerous health benefits for the infant, including a boosted immune system, lower incidence of ear infections and respiratory diseases, and potential long-term protection against chronic conditions like obesity and diabetes.*
- *Breastfeeding also provides significant health benefits for the mother, such as helping the uterus return to its normal size, strengthening bones, and reducing her risk of developing certain cancers and Type 2 diabetes.*
- *While breast milk is ideal for most infants, some mothers may face barriers such as physical discomfort or lack of support. In rare cases, breastfeeding may be medically contraindicated, such as for mother with HIV (in developed countries) or infants with the genetic disorder galactosemia.*

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13.4

Nutrition Recommendations for Infants

13.4 Nutrition Recommendations for Infants

Diet and nutrition have a major impact on a child's development from infancy into the adolescent years. A healthy diet not only affects growth, but also immunity, intellectual capabilities, and emotional well-being. One of the most important jobs of parenting is making sure that children receive an adequate amount of needed nutrients to provide a strong foundation for the rest of their lives.

Nutritional Requirements

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

Energy

Energy needs relative to size are much greater in an infant than an adult. The RDA to meet energy needs changes as an infant matures and puts on more weight. For example, the equation for the first three months of life is (89 x weight [kg] −100) + 175 kcal. Based on these equations, the estimated energy requirement for infants from zero to six months of age is 472 to 645 Calories per day for boys and 438 to 593 Calories per day for girls. For infants ages six to twelve months, the estimated requirement is 645 to 844 Calories per day for boys and 593 to 768 Calories per day for girls.[27] How often infants want to eat will also change over time due to growth spurts, which typically occur at about two weeks and six weeks of age, and again at about three months and six months of age.

Macronutrients

The dietary recommendations for infants are based on the nutritional content of human breast milk. Almost all of the carbohydrate in human milk is lactose, which infants digest and tolerate well. Between four to six months, it is appropriate to



Figure 13.8 Mother feeds infant. Image by AL.

start introducing additional food sources of carbohydrates such as cereal grains, fruits and vegetables. Added sugars are not recommended. The protein DRI recommendation for infants ages two to six months is 1.52 g/kg/day and for infants seven to twelve (12) months is 1.2 g/kg/day compared to the adult RDA of 0.8 g/kg/day.[28] Pureed or ground meat and beans may be added at 6 months to provide protein and iron.

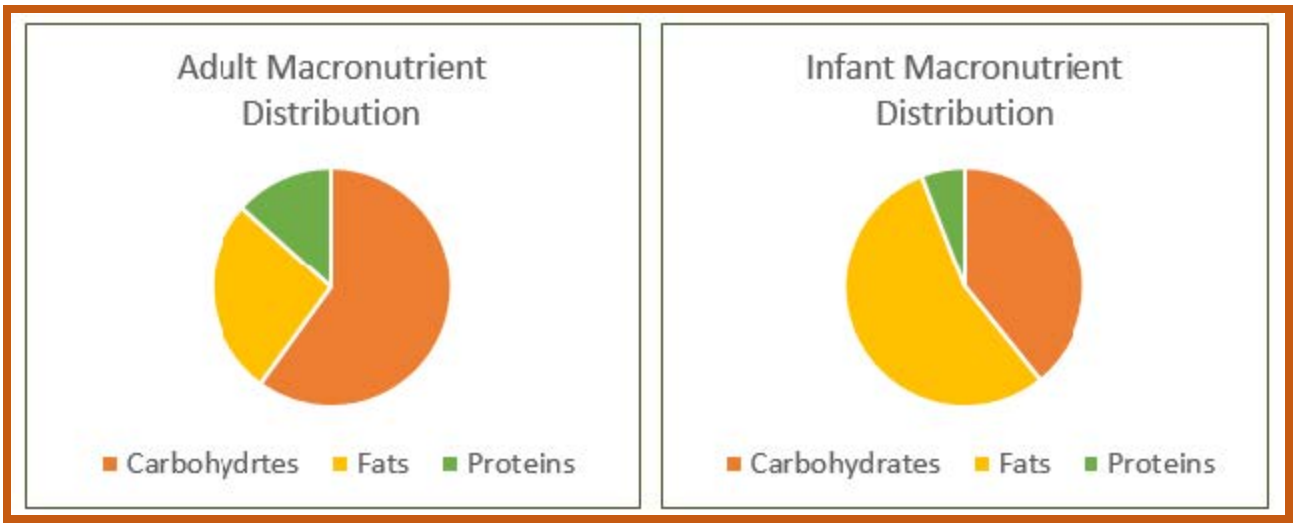


Table 13.3 Comparison of adult and infant macronutrient distribution. Adults' needs are very different than that of an infant. An infant's diet is very energy dense to ensure adequate intake of calories in a smaller volume

Fat is the major source of calories for infants fed human breast milk. The energy density fat provides for the infant is important for the rapid growth and development that occurs during infancy. The recommendation of fat is based on the average composition of breastmilk, which is approximately 55% of calories consumed in a day. Breast milk also contains the essential fatty acid, DHA. Increasing evidence shows that infants fed breast milk with a higher content of DHA have better eye and brain development. For this reason, it is important for lactating mothers to consume adequate amounts of DHA.[29]

Fluids

Infant's needs for fluids are higher than adults because of their increased surface area for size and they also excrete more urine because their kidneys are not fully mature. However, infants that are exclusively breastfed do not require additional water. If water losses are increased due to diarrhea or vomiting, additional fluids may be needed.[30]

Micronutrients

Almost all of the nutrients that infants require can be met if they consume an adequate amount of breast milk. There are a few exceptions, though. Human milk is low in vitamin D, which is needed for calcium absorption and building bone, among other things. Therefore, breastfed children often need to take a vitamin D supplement in the form of drops. Infants at the highest risk for vitamin D deficiency are those with darker skin and no exposure to sunlight.

Breast milk is also low in vitamin K, which is required for blood clotting, and deficits could lead to bleeding or hemorrhagic disease. Babies are born with limited vitamin K, so some states require a vitamin K injection after birth.

Breast milk is not a good source of iron, but the iron in breast milk is well absorbed by infants. Although formula has more iron than breast milk, the iron in breast milk is more bioavailable. Nearly 80% of the iron a healthy term infant is born with was transferred to the baby during the third trimester of pregnancy. While this storage of iron may be sufficient for about four to six months, an infant needs an additional source of iron other than breast milk after that age. [31] After that point, the RDA for iron is 11 mg/day.[10]

Current recommendations by the American Academy of Pediatrics states that infants under six months of age should not receive fluoride supplements whether they are breast-fed or formula-fed. Older infants and children then should have appropriate supplementation if the local water provides less than 30 parts per million of fluoride.[32] Toothpaste with fluoride is

generally recommended as well. A smear, or size of a grain of rice, should be used up to age three. Older children should limit the size of their toothpaste to the size of a pea.[33]

Introducing solid foods

Is my baby ready for solid foods?
Can he hold his head up?
Does he open his mouth when food comes his way?
Can he move food from the spoon into his throat?
Is he big enough? (generally double birth weight of 13 pounds)

Table 13.4: Signs a baby is ready for solid

Infants should be breastfed or bottle-fed exclusively for the first six months of life according to the WHO. (The American Academy of Pediatrics recommends breast milk or bottle formula exclusively for at least the first four months, but ideally for six months.) Infants should not consume solid foods prior to six months because there is a risk of choking and solids do not contain the right composition of nutrients infants need. Also, eating solids may mean drinking less breast milk or bottle formula. If that occurs, an infant may become malnourished.

If parents try to feed an infant who is too young or is not ready, their tongue will push the food out, which is called an extrusion reflex. After six months, the suck-swallow reflexes are not as strong, and infants can hold up their heads and move them around, both of which make eating solid foods more feasible.

Solid baby foods can be bought commercially or prepared from regular food using a food processor, blender, food mill, or grinder at home as long as food safety guidelines are followed. Usually, an infant cereal can be offered from a spoon at four to six months. By nine months to a year, infants are able to chew soft foods and can eat solids that are well chopped or mashed.

Iron-fortified cereals, such as rice cereal, are often offered first between four and six months to help replenish depleted iron stores. The 2020 Dietary Guidelines for Americans recommends introducing potentially allergenic foods (for example, eggs, peanuts, shellfish, tree nuts) along with a variety of other solid foods. The DGA also recommends avoiding honey (addressed below), unpasteurized foods and beverages and limiting added sodium and sugars. [35]

Feeding problems in infancy

Parents and caregivers should be mindful of certain diet-related problems that may arise during infancy. Certain foods are choking hazards, including foods with skins or foods that are very small, such as grapes. Other examples of potential choking hazards include raw carrots and apples, raisins, and hard candy. Parents should also avoid adding salt or seasonings to an infant's food.

Heating an infant's food presents a risk of accidental injury or burns, which may occur if the food is heated unevenly or excessively. Keep in mind that an infant cannot communicate that the food



Figure 13.9 Baby food can be pre-prepared or made at home. Image by AL.



Figure 13.10 Washing produce helps prevent foodborne illnesses such as infantile botulism. Image by Any Lane on Pexels.

is too hot. Also, parents and caregivers should never leave a baby alone at mealtime, because an infant can accidentally choke on pieces of food that are too big or have not been adequately chewed. Honey has been identified as a source of a specific spore which is called Clostridium botulinum. The spores can produce a poisonous toxin in a baby's immature intestines which can cause **infantile botulism** causing the baby to become very weak and sick. For this reason, it is recommended to not provide honey to an infant before age one.[35] However, honey as an ingredient in food, such as in cereal, is safe for all ages because it has been adequately heat treated. It is important to note that botulinum exists in the environment and has been found on fresh fruits and vegetables. This is a good reminder that using good food safety practices such as washing fruits and vegetables is also important.[36]

Assessing Growth

Healthy infants grow steadily, but not always at an even pace. For example, during the first year of life, height increases by 50 percent, while weight triples. Physicians and other health professionals can use growth charts to track a baby's development process. Because infants cannot stand, length is used instead of height to determine the rate of a child's growth. Other important developmental measurements include head circumference and weight. All of these must be tracked and compared against standard measurements for an infant's age. Nationally accepted growth charts are based on data collected by the National Center for Health Statistics.[37] These charts allow for tracking trends over time and comparing with other infants among percentiles within the United States. Growth charts may provide warnings that a child has a medical problem or is malnourished. Insufficient weight or height gain during infancy may indicate a condition known as failure-to-thrive (FTT), which is characterized by poor growth. FTT can happen at any age, but in infancy, it typically occurs after six months. Some causes include poverty, lack of enough food, feeding inappropriate foods, and excessive intake of fruit juice.

Measuring and tracking an infant's growth is one of the best ways to monitor if the child is receiving adequate nutrition. Common measurements during the first year of life are length-forage, weight-for-age, length-for-weight and head circumference-for-age. To best identify proper growth, it is best to plot these measurements on a growth chart. For infants, the charts that are recommended to use are the World Health Organization (WHO) growth charts. These charts were developed using infants that were exclusively breastfed for at least 4 months. The percentiles in the WHO growth charts better reflect the pattern set by following recommendations regarding breastfeeding. The Centers for Disease Control (CDC) charts were developed tracking growth of infants that were not necessarily breastfed for the recommended amount of time. It is recommended to use the WHO growth charts until the age of two. [37] Percentiles reflect how children grow compared to children with the same age and gender. For example, a 3-month-old baby girl plotted at the 30 th percentile indicates that out of 100 3-month-old baby girls, 30 would be smaller and 70 would be larger. The goal is to have a child follow their growth curve or percentile. Without using growth charts, two "checkpoints" can be monitored to do a less detailed assessment of

weight and nutritional status. Normal growth would be indicated by the baby's weight doubling by about 5 months and tripling by one year of age. [38]

Key Takeaways

- *Infants have higher macronutrient and micronutrient needs relative to their size than at any other stage of life, and for the first six months, these needs are best met by breast milk or formula.*
- *While breast milk provides most essential nutrients, it is low in Vitamin D, Vitamin K, and iron, which may require supplementation or the introduction of fortified foods after about six months of age.*
- *Solid foods should not be introduced before 6 months of age to prevent choking and ensure the infant receives adequate nutrition from breast milk or formula. The first solid foods are often iron-fortified cereals.*
- *Parents should be aware of foods that are choking hazards and specific dangers like infantile botulism, which is why honey should not be given to infants under one year old.*
- *An infant's growth should be closely monitored using growth charts, as a significant change in their growth curve can be a sign of a medical or nutritional problem.*

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13.5

Nutrition Recommendations for Young Children

13.5 Nutrition Recommendations for Young Children

By the age of two, children have advanced from infancy and are on their way to becoming school-aged children. Their physical growth and motor development slows compared to the progress they made as infants. However, toddlers experience enormous intellectual, emotional, and social changes. Of course, food and nutrition continue to play an important role in a child's development. During this stage, the diet completely shifts from breastfeeding or bottle-feeding to solid foods along with healthy juices and other liquids. Parents of toddlers also need to be



Figure 13.12 Young children preparing a healthy snack. Image by ZakiAlewadi on pixabay.

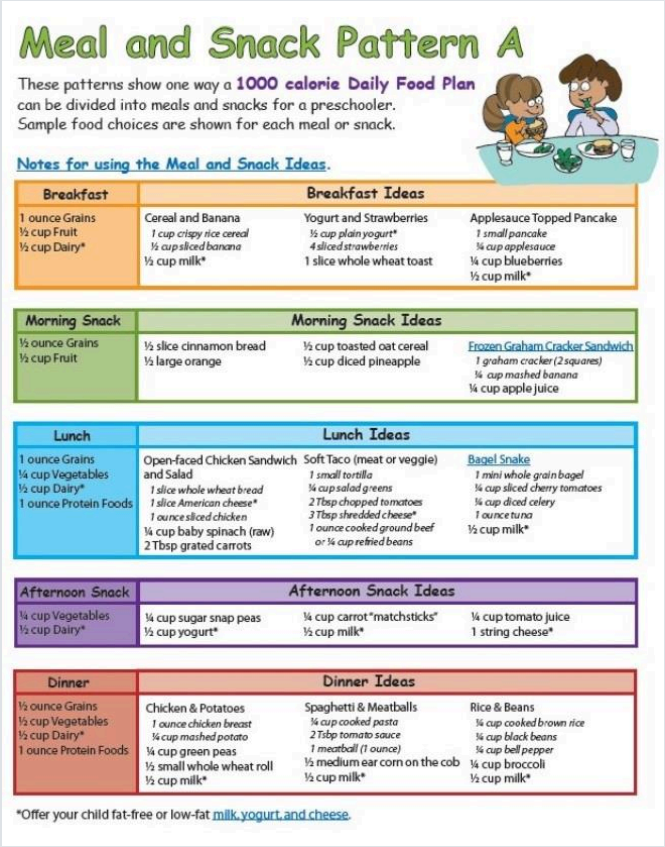
mindful of certain nutrition-related issues that may occur during this stage of the human life cycle.

During this phase of human development, children are mobile and grow more slowly than infants, but are much more active. The toddler years pose interesting challenges for parents or other caregivers, as children learn how to eat on their own and

begin to develop personal preferences. However, with the proper diet and guidance, toddlers can continue to grow and develop at a healthy rate.

Energy

The energy requirements for children from ages two to three are about 1,000 to 1,400 Calories a day. In general, a toddler needs to consume about 40 Calories for every inch of height. For example, a young child who measures 32 inches should take in an average of 1,300 Calories a day. However, the recommended caloric intake varies with each child's level of activity. Toddlers require small, frequent, nutritious snacks and meals to satisfy energy requirements. The amount of food a toddler needs from each food group depends on daily caloric needs. The following figure (Figure 3) describes how a 1000 Calorie meal pattern could be arranged to provide the needs for a child of this age.[39]



Meal and Snack Pattern A

These patterns show one way a **1000 calorie Daily Food Plan** can be divided into meals and snacks for a preschooler. Sample food choices are shown for each meal or snack.

Notes for using the Meal and Snack Ideas.

Breakfast	Breakfast Ideas		
1 ounce Grains ½ cup Fruit ½ cup Dairy*	Cereal and Banana *1 cup crispy rice cereal* *½ cup sliced banana* ½ cup milk*	Yogurt and Strawberries *½ cup plain yogurt** *4 sliced strawberries* 1 slice whole wheat toast	Applesauce Topped Pancake *1 small pancake* *¼ cup applesauce* ¼ cup blueberries ½ cup milk*

Morning Snack	Morning Snack Ideas		
½ ounce Grains ½ cup Fruit	½ slice cinnamon bread ½ large orange	½ cup toasted oat cereal ½ cup diced pineapple	Frozen Graham Cracker Sandwich *1 graham cracker (2 squares)* *¼ cup mashed banana* ¼ cup apple juice

Lunch	Lunch Ideas		
1 ounce Grains ¼ cup Vegetables ½ cup Dairy* 1 ounce Protein Foods	Open-faced Chicken Sandwich and Salad *1 slice whole wheat bread* *1 slice American cheese** *1 ounce sliced chicken* ¼ cup baby spinach (raw) 2 Tbsp grated carrots	Soft Taco (meat or veggie) *1 small tortilla* *¼ cup salad greens* *2 Tbsp chopped tomatoes* *3 Tbsp shredded cheese** *1 ounce cooked ground beef* *or ¼ cup refried beans*	Bagel Snake *1 mini whole grain bagel* *¼ cup sliced cherry tomatoes* *¼ cup diced celery* *1 ounce tuna* ½ cup milk*

Afternoon Snack	Afternoon Snack Ideas		
¼ cup Vegetables ½ cup Dairy*	¼ cup sugar snap peas ½ cup yogurt*	¼ cup carrot "matchsticks" ½ cup milk*	¼ cup tomato juice 1 string cheese*

Dinner	Dinner Ideas		
½ ounce Grains ½ cup Vegetables ½ cup Dairy* 1 ounce Protein Foods	Chicken & Potatoes *1 ounce chicken breast* *¼ cup mashed potato* ¼ cup green peas ½ small whole wheat roll ½ cup milk*	Spaghetti & Meatballs *¼ cup cooked pasta* *2 Tbsp tomato sauce* *1 meatball (1 ounce)* ½ medium ear corn on the cob ½ cup milk*	Rice & Beans *¼ cup cooked brown rice* *¼ cup black beans* *¼ cup bell pepper* ¼ cup broccoli ½ cup milk*

*Offer your child fat-free or low-fat milk, yogurt, and cheese.

I don't know if the image is good to use. We might need to find something else. *Figure 13.13: 1000 Calorie meal and snack pattern for preschoolers*[39]

Macronutrients

For carbohydrate intake, the Acceptable Macronutrient Distribution Range (AMDR) is 45 to 65 percent of daily calories (113 to 163 grams of carbohydrate per 1,000 Calories). Toddlers' needs increase to support their body and brain development. Brightly colored unrefined carbohydrates, such as peas, orange slices, tomatoes, and bananas are not only nutrient dense, they also make a plate look more appetizing and appealing to a young child. The AMDR for protein is 5 to 20 percent of daily calories (13 to 50 grams of protein per 1,000 Calories). The AMDR for fat for toddlers is 30 to 40 percent of daily calories (33 to 44 grams of fat per 1,000 Calories). Essential fatty acids are vital for the development of the eyes, along with nerve and other types of tissue.[10]



Figure 13.14: Children eating a healthy breakfast. Image by Alex Green on Pexels.

Micronutrients



As a child grows bigger, the demands for micronutrients increase. These needs for vitamins and minerals can be met with a balanced diet, with a few exceptions. The RDA for toddlers is 15 micrograms of vitamin D per day.10 Vitamin D-fortified milk can help to meet this need. However, toddlers who do not get enough of this micronutrient may be advised to take a supplement. Along with Vitamin D, calcium plays an important role in the development of healthy bones and to help children achieve their optimal peak bone mass.40 Pediatricians may also prescribe a fluoride supplement for toddlers who live in areas with fluoride-poor water.

Iron deficiency is also a major concern for children between the ages of two and three. An infant who switches to solid foods, but does not eat enough iron-rich foods, can develop iron-deficiency anemia. This condition occurs when an iron-deprived body cannot produce enough hemoglobin, a protein in red blood cells that transports oxygen throughout the body. The inadequate supply of hemoglobin for new blood cells results in anemia. Iron-deficiency anemia causes a number of problems including weakness, pale skin, shortness of breath, and irritability. It can also result in intellectual, behavioral, or motor problems. In infants and toddlers, iron-deficiency anemia can occur when older babies are weaned from breast milk and iron-fortified formula and not given good sources of iron in foods. As a result, their iron stores become diminished at a time when this nutrient is critical for brain growth and development.[41]

Figure 13.15 Examples of iron sources. Created by AP.

There are steps that parents and caregivers can take to prevent iron-deficiency anemia, such as adding more iron-rich foods to a child's diet, including lean meats, fish, poultry, eggs, legumes, and iron-enriched whole-grain breads and cereals. A

toddler's diet should provide 7 to 10 milligrams of iron daily. Milk is a poor source of iron but provides an excellent source of calcium. It is recommended for children to consume 16 fluid ounces (470 milliners) but not exceed 24 fluid ounces (710 milliliters) of milk per day to provide calcium but avoid displacing foods rich with iron.[40, 41, 42] Children may also be given a daily supplement, using infant vitamin drops with iron or ferrous sulfate drops if advised by a doctor. Consuming vitamin C, such as orange juice, can also help to improve iron absorption.[43]

Toddler Diarrhea

A variety of conditions or circumstances may give a toddler diarrhea. Possible causes include bacterial or viral infections, food allergies, or lactose intolerance, among other medical conditions. Excessive fruit juice consumption (more than one 6-ounce cup per day) can also lead to diarrhea.[43] Diarrhea presents a special concern in young children because their small size makes them more vulnerable to dehydration. Parents should contact a pediatrician if a toddler has had diarrhea for more than twenty-four hours, if a child is also vomiting, or if they exhibit signs of dehydration, such as a dry mouth or tongue, or sunken eyes, cheeks, or abdomen. Preventing or treating dehydration in toddlers includes the replacement of lost fluids and electrolytes (sodium and potassium). Oral rehydration therapy, or giving special fluids by mouth, is the most effective measure. Figure 4 describes the recommendations from the American Academy of Pediatrics for juice consumption for children of all ages.

JUICE RECOMMENDATIONS FOR INFANTS, CHILDREN AND ADOLESCENTS		
AGE	AMOUNT PER DAY	ADDITIONAL RECOMMENDATIONS
Younger than 12 months	None	Fruit juice is unnecessary for children under 1 year of age. Human breast milk or formula is sufficient for infants.
1 to 3 years	Maximum: 4oz (1/2 cup)	Do not allow child to carry juice in bottle, "sippy cups" or juice boxes throughout the day. Do not offer juice at bedtime.
4 to 6 years	Maximum: 4-6 oz (1/2 cup to 3/4 cup)	As with younger children, do not allow them to carry juice with them and have access throughout the day. Encourage intake of whole fruit.
7 - 18 years	Maximum: 8 oz (1 cup)	Continue to encourage intake of whole fruit over fruit juice. Excess consumption of fruit juice can lead to excess weight gain at all ages.

Adapted from recommendations from the American Academy of Pediatrics Table13.5 Juice Recommendations from the Academy of Pediatrics43

Food Jags

For weeks, toddlers may go on a **food jag** and eat one or two preferred foods—and nothing else. It is important to understand that preferences will be inconsistent as a toddler develops eating habits. This is one way that young children can assert their individuality and independence. However, parents and caregivers should be concerned if the same food jag persists for several months, instead of several weeks. Options for addressing this problem include rotating acceptable foods while continuing to offer diverse foods, remaining low-key to avoid exacerbating the problem, and discussing the issue with a pediatrician. Also, children should not be forced to eat foods that they do not want. It is important to remember that food jags do not have a long-term effect on a toddler's health, and are usually temporary situations that will resolve themselves.[44]

Dental Caries

Early childhood caries remains a potential problem during the toddler years. The risk of early childhood caries continues as children begin to consume more foods with a high sugar content. According to the National Health and Nutrition Examination Survey, children between ages of two and five consume about 200 Calories of added sugar per day.[45] Therefore, parents with toddlers should avoid processed foods, such as snacks from vending machines, and sugary beverages, such as soda. Parents also need to instruct a child on brushing their teeth at this time to help a toddler develop healthy habits and avoid tooth decay.

Choking Hazards

Certain foods are difficult for toddlers to manage and pose a high risk of choking. Big chunks of food should not be given to children under the age of four. Also, globs of peanut butter can stick to a younger child's palate and choke them. Popcorn and nuts should be avoided as well, because toddlers are not able to grind food and reduce it to a consistency that is safe for swallowing. Certain raw vegetables, such as baby carrots, whole cherry tomatoes, whole green beans, and celery are also choking hazards. However, there is no reason that a toddler cannot enjoy well-cooked vegetables cut into bite-size pieces.

Developing Healthy Habits

During the toddler years, parents may face a number of problems related to food and nutrition. Possible obstacles include difficulty helping a young child overcome a fear of new foods, or fights over messy habits at the dinner table. It may take a child being exposed to a new food 8-10 times before it is accepted.[46,47] Even in the face of problems and confrontations, parents and other caregivers must make sure their preschooler has nutritious choices at every meal. For example, even if a child stubbornly resists eating vegetables, parents should continue to provide them. Before long, the child may change their mind, and develop a taste for foods once abhorred. It is important to remember this is the time to establish or reinforce healthy habits.

Eating habits develop early in life. They are typically formed within the first few years and it is believed that they persist for years, if not for life. For that reason, it is important for parents and other caregivers to help children establish healthy habits and avoid problematic ones. Children begin expressing their preferences at an early age. Parents must find a balance between providing a child with an opportunity for self-expression, helping a child develop healthy habits, and making sure that a child meets all of their nutritional needs.

Registered Dietitian Nutritionist Ellyn Satter states that feeding is a responsibility that is split between parent and child.[47] The **division of responsibility** is outlined in the following table:

Parent's Responsibility	Child's Responsibility
What children eat	*How much* they eat
When children eat	*Whether* they eat
Where children eat	

Table 13.6 Division of Responsibility of eating as described by Ellyn Satter, RDN[47]

Satter states the role of the parent or caregiver in feeding includes:

- selecting and preparing food

- providing regular meals and snacks
- making mealtimes pleasant
- showing children what they must learn about mealtime behavior
- avoiding letting children eat in between meal- or snack-times[48]

Following Satter's division of responsibility in feeding can help a child eat the right amount of food, learn mealtime behavior, and grow at a healthy and predictable rate.

The Family: A Proclamation to the World describes the **stewardship** of parents by stating, "Parents have a sacred duty to rear their children in love and righteousness, to provide for their physical and spiritual needs, and to teach them to love and serve one another, observe the commandments of God, and be law-abiding citizens wherever they live."[49]

Parents are encouraged to provide a loving environment and learning opportunities for their children to help them grow and learn. We learn from the same revelation that [we accepted] "His plan by which His children could obtain a physical body and gain earthly experience to progress toward perfection and ultimately realize their divine destiny as heirs of eternal life."[49]

God has given us the gift of **agency**, or the ability and privilege to choose and act for ourselves, to help us grow. Agency is essential in the plan of salvation. Without agency, we would not be able to learn or progress or follow the Savior.[49]

When parents apply this council to the feeding process, children can learn at an early age how to make choices. The following table compares these two ideas and how to implement the feeding relationship process to teach children in a loving environment.

	Stater's Division of Responsibility in Eating	**The Family: A Proclamation to the World**
Parent	Provide *what* children eat Decided *when* children eat (meal and snack times) Determine *where* children will eat	Stewardship: Provide Choices Teach correct principles Loving Environment
Child	Decide *how* much to eat Determine *whether* to eat (hungry or not?)	Agency: Make choices Learn from experience Be respectful

Table 13.7: Satter's Division of Responsibility of eating compared to principles outlined in The Family: A Proclamation to the World[48, 49]

Providing learning opportunities in a safe environment allows children to make choices when the consequences are low. This can teach them the skill of decision making and can be valuable as children make more difficult decisions. Bad habits and poor nutrition have negative outcomes. However, forming good habits at a young age will also have positive effect as children grow. The foods you consume in your younger years will impact your health as you age, from childhood into the later stages of life. As a result, good nutrition today means optimal health tomorrow.

Nutrition recommendations to promote health and prevent disease vary in different stages of life. The following table illustrates that recommendations change based on age, gender and stage of life. A complete list can be found using the DRI tables discussed throughout the text. More in depth recommendations can be studied in other life cycle approach nutrition courses.

LIFE STAGE	PROTEIN (g/kg/day)	VITAMIN C (mg/day)	VITAMIN D (mcg/day)	FOLATE (mcg/day)	CALCIUM (mg/day)	IRON (mg/day)
0-6 years	1.52*	40*	10*	65*	200*	0.27*
4-8 years	**0.95**	**25**	**15**	**200**	**1000**	**10**
Males 14-18 years	**0.85**	**75**	**15**	**400**	**1300**	**11**
Females 14-18 years	**0.80**	**65**	**15**	**400**	**1300**	**15**
Males 19-30 years	**0.80**	**90**	**15**	**400**	**1000**	**8**
Females 19-30 years	**0.80**	**75**	**15**	**400**	**1000**	**18**
Males > 70 years	**0.80**	**90**	**20**	**400**	**1200**	**8**
Females > 70 years	**0.80**	**75**	**20**	**400**	**1200**	**8**
Pregnant 19-30 years	**1.1**	**85**	**15**	**600**	**1000**	**27**
Lactating 19-30 years	**1.3**	**120**	**15**	**500**	**1000**	**9**

g = grams, mg = milligrams, mcg = micrograms, IU = International Units, DFE = Dietary Folate Equivalents, NE = Niacin Equivalents, % = Percent (%) of a 2000 calorie diet

*indicates AI recommendations. Bold Values Indicate RDA recommendations.

Table 13.8: DRIs showing changes during the life span[10]

Key Takeaways

- *Toddlers have high energy needs relative to their size, requiring about 1,000-1,400 calories per day, which should be met with small, frequent, and nutritious meals and snacks.*
- *A major nutritional concern for young children is iron-deficiency anemia, which can cause a number of health problems. It is recommended to provide iron-rich foods and limit milk intake to a specific amount to ensure adequate iron absorption.*
- *Parents should be mindful of choking hazards and risks like dental caries from high sugar intake. Excessive fruit juice consumption can also lead to diarrhea.*
- *Food jags, where a child will eat only a few specific foods for a period of time, are a normal and temporary behavior. Parents should continue to offer a variety of healthy foods without forcing the child to eat them.*
- *The Division of Responsibility in Feeding recommends that the parent decide what, when, and where a child eats, while the child decides how much to eat and whether to eat at all. This helps a child develop a healthy relationship with food.*

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