

CHAPTER 2. THE HUMAN BODY

Introduction

I ola no ke kino i ka mā'ona o ka 'ōpū

The body enjoys health when the stomach is full



Image by Henrique Felix on unsplash.com / CC0

Learning Objectives

By the end of this chapter, you will be able to:

- Explain the anatomy and physiology of the digestive system and other supporting organ systems
- Describe the relationships between each of the organ systems

The Native Hawaiians believed there was a strong connection between health and food. Around the world, other cultures had similar views of food and its relationship with health. A famous quote by the Greek physician Hippocrates over two thousand years ago, “Let food be thy medicine and medicine be thy food” bear much relevance on our food choices and their connection to our health. Today, the scientific community echoes Hippocrates’ statement as it recognizes some foods as functional foods. The Academy of Nutrition and Dietetics defines functional foods as “whole foods and fortified, enriched, or enhanced foods that have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis, at effective levels.”

In the latter nineteenth century, a Russian doctor of immunology, Elie Metchnikoff, was intrigued by the healthy life spans of people who lived in the tribes of the northern Caucasus Mountains. What contributed to their long lifespan and their resistance to life-threatening diseases? A possible factor lay wrapped up in a leather satchel used to hold fermented milk. Observing the connection between the beverage and longevity, Dr. Elie Metchnikoff began his research on beneficial bacteria and the longevity of life that led to his book, *The Prolongation of Life*. He studied the biological effects and chemical properties of the kefir elixir whose name came from the Turkish word “kef” or “pleasure.” To this day, kefir is one of the most widely enjoyed beverages in Russia.

Kefir has since found its way into America, where it is marketed in several flavors and can be found at your local grocery store. It is one product of the billion-dollar functional food industry marketed with all sorts of health claims from improving digestion to preventing cancer. What is the scientific evidence that kefir is a functional food? Expert nutritionists agree that probiotics, such as kefir, reduce the symptoms of lactose intolerance and can ward off virally caused diarrhea. While some health claims remain unsubstantiated, scientific studies are ongoing to determine the validity of other health benefits of probiotics.

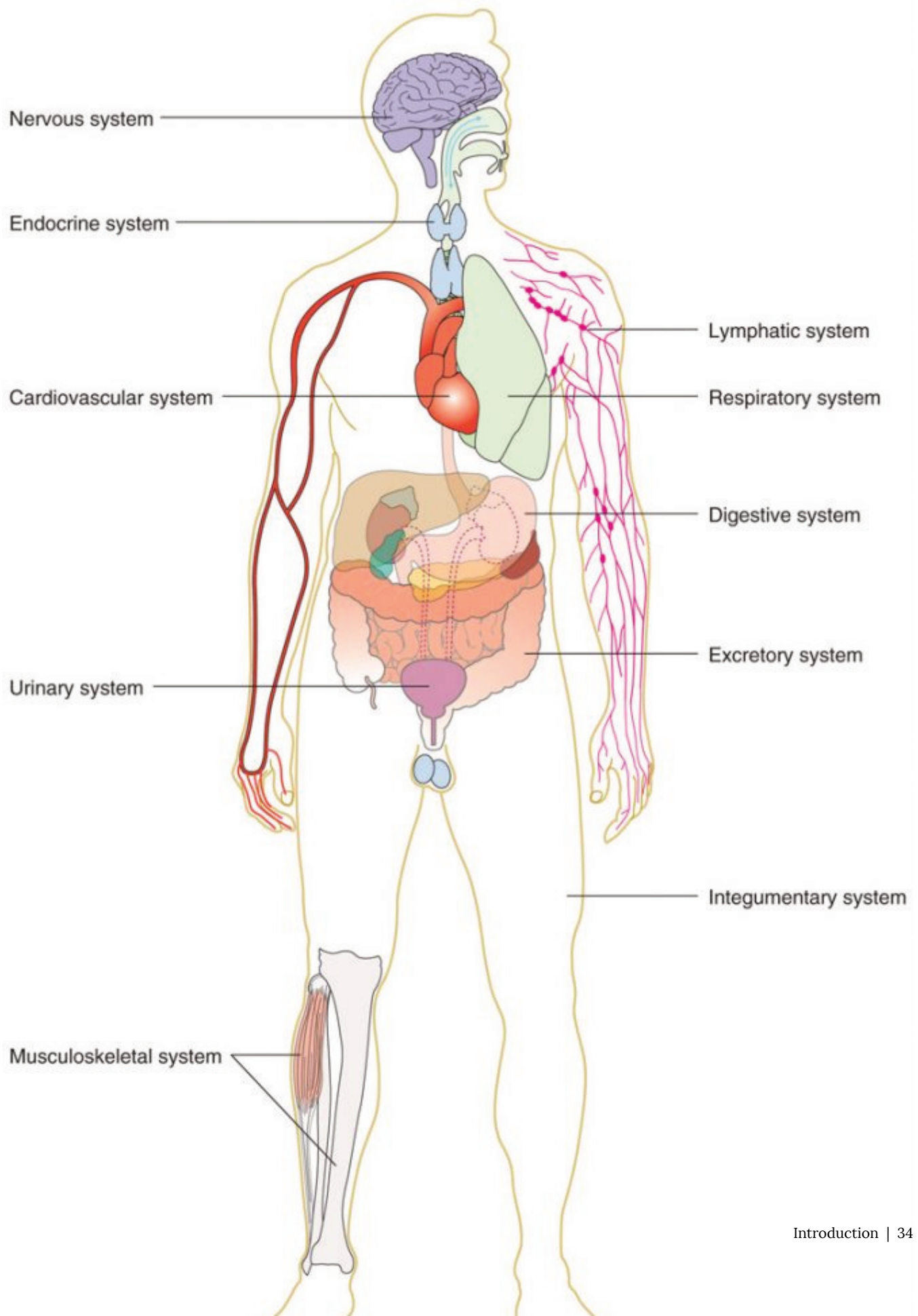
The Native Hawaiians also consumed a daily probiotic in their diet commonly known as poi (pounded taro). In precolonial Hawai‘i, poi was used for a wide variety of dietary and medicinal purposes. Aside from poi’s nutrient dense composition, fermented poi has numerous compounds created in the fermentation process that are very beneficial to the health of the human body. As a probiotic, evidence suggests that poi can be useful in helping diseases such as diarrhea, gastroenteritis, irritable bowel syndrome, inflammatory bowel disease, and cancer.¹

Another well-known probiotic to the local people of Hawai‘i is Kimchi. Kimchi is a traditional Korean food that is manufactured by fermenting vegetables (usually cabbage). Similar to the kefir and poi, kimchi also has shown to have similar health benefits as a probiotic food.²

The Japanese also have traditional fermented foods such as natto. Natto is made from fermented soybeans and has many health benefits as a probiotic. Along with the beneficial components, natto is very nutrient-dense containing

carbohydrates, fats, protein, fiber, vitamins and minerals.³ Other common foods we ferment in our diet include miso, sauerkraut, kombucha, and tempeh.

Figure 2.1 Components of Organ Systems in the Human Body



Knowing how to maintain the balance of friendly bacteria in your intestines through proper diet can promote overall health. Recent scientific studies have shown that probiotic supplements positively affect intestinal microbial flora, which in turn positively affect immune system function. As good nutrition is known to influence immunity, there is great interest in using probiotic foods and other immune-system-friendly foods as a way to prevent illness. In this chapter we will explore not only immune system function, but also all other organ systems in the human body. We will learn the process of nutrient digestion and absorption, which further reiterates the importance of developing a healthy diet to maintain a healthier you. The evidence abounds that food can indeed be “thy medicine.”

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Notes

1. Brown A, Valiere A. The Medicinal Uses of Poi. *Nutrition in Clinical Care*. 2004; 7(2), 69-74. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1482315/>. Accessed September 20, 2017.
2. Park K, Jeong J, et al. Health Benefits of Kimchi. *Journal of Medicinal Food*. 2014; 17(1), 6-20. <https://www.ncbi.nlm.nih.gov/pubmed/24456350>. Accessed September 20, 2017.
3. Sanjukta S, Rai AK. Production of bioactive peptides during soy fermentation and their potential health benefits. *Trends in Food Science and Technology*. 2016; 50, 1-10. <http://www.sciencedirect.com/science/article/pii/S0924224415300571>. Accessed September 20, 2017.

Basic Biology, Anatomy, and Physiology

THE BASIC STRUCTURAL AND FUNCTIONAL UNIT OF LIFE: THE CELL

What distinguishes a living organism from an inanimate object? A living organism conducts self-sustaining biological processes. A cell is the smallest and most basic form of life.

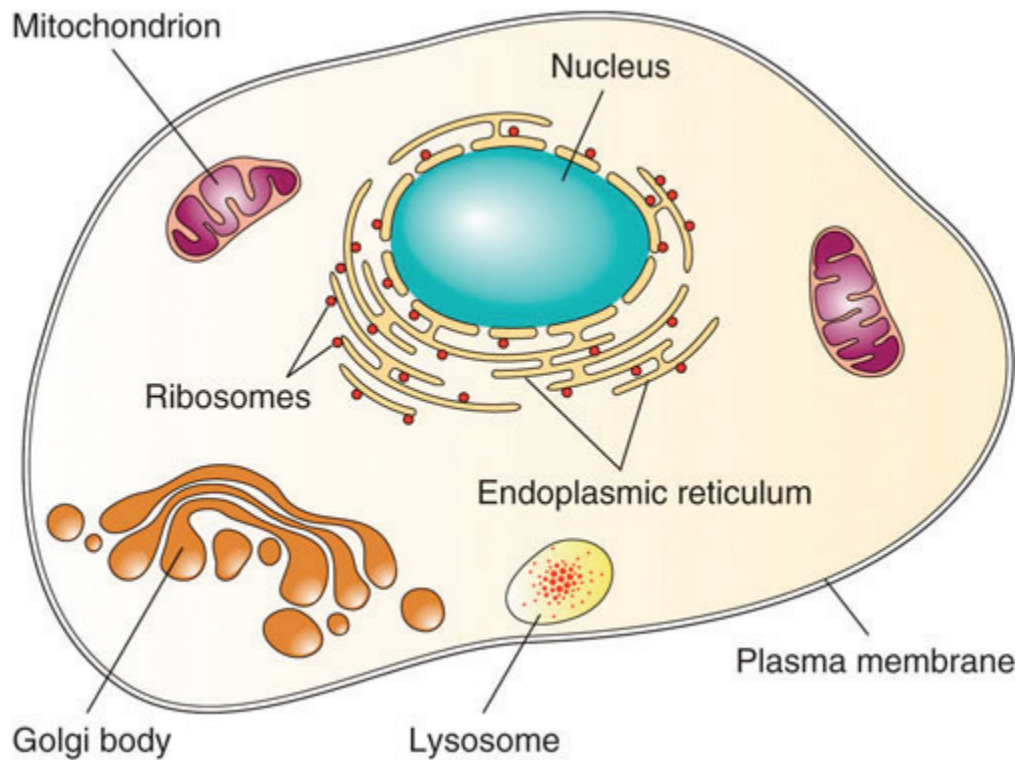
The cell theory incorporates three principles:

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

Independent single-celled organisms must conduct all the basic processes of life. The single-celled organism must take in nutrients (energy capture), excrete wastes, detect and respond to its environment, move, breathe, grow, and reproduce. Even a one-celled organism must be organized to perform these essential processes. All cells are organized from the atomic level to all its larger forms. Oxygen and hydrogen atoms combine to make the molecule water (H₂O). Molecules bond together to make bigger macromolecules. The carbon atom is often referred to as the backbone of life because it can readily bond with four other elements to form long chains and more complex macromolecules. Four macromolecules—carbohydrates, lipids, proteins, and nucleic acids—make up all of the structural and functional units of cells.

Although we defined the cell as the “most basic” unit of life, it is structurally and functionally complex (Figure 2.2 “The Cell Structure”). A cell can be thought of as a mini-organism consisting of tiny organs called organelles. The organelles are structural and functional units constructed from several macromolecules bonded together. A typical animal cell contains the following organelles: the nucleus (which houses the genetic material DNA), mitochondria (which generate energy), ribosomes (which produce protein), the endoplasmic reticulum (which is a packaging and transport facility), and the golgi apparatus (which distributes macromolecules). In addition, animal cells contain little digestive pouches, called lysosomes and peroxisomes, which break down macromolecules and destroy foreign invaders. All of the organelles are anchored in the cell's cytoplasm via a cytoskeleton. The cell's organelles are isolated from the surrounding environment by a plasma membrane.

Figure 2.2 The Cell Structure



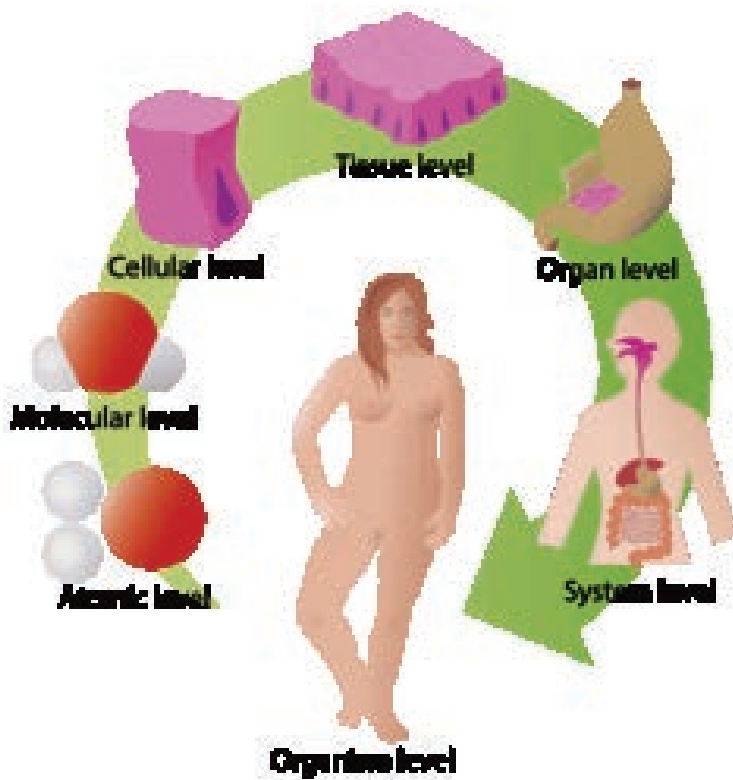
The cell is structurally and functionally complex.

TISSUES, ORGANS, ORGAN SYSTEMS, AND ORGANISMS

Unicellular (single-celled) organisms can function independently, but the cells of multicellular organisms are dependent upon each other and are organized into five different levels in order to coordinate their specific functions and carry out all of life's biological processes (see Figure 2.3 "Organization of Life").

- Cells are the basic structural and functional unit of all life. Examples include red blood cells and nerve cells. There are hundreds of types of cells. All cells in a person contain the same genetic information in DNA. However, each cell only expresses the genetic codes that relate to the cell's specific structure and function.
- Tissues are groups of cells that share a common structure and function and work together. There are four basic types of human tissues: connective, which connects tissues; epithelial, which lines and protects organs; muscle, which contracts for movement and support; and nerve, which responds and reacts to signals in the environment.
- Organs are a group of tissues arranged in a specific manner to support a common physiological function. Examples include the brain, liver, and heart.
- Organ systems are two or more organs that support a specific physiological function. Examples include the digestive system and central nervous system. There are eleven organ systems in the human body (see Table 2.1 "The Eleven Organ Systems in the Human Body and Their Major Functions").
- An organism is the complete living system capable of conducting all of life's biological processes.

Figure 2.3 Organization of Life



“Organization Levels of Human Body” by Laia Martinez / CC BY-SA 4.0

Table 2.1 The Eleven Organ Systems in the Human Body and Their Major Functions

Organ System	Organ Components	Major Function
Cardiovascular	heart, blood/lymph vessels, blood, lymph	Transport nutrients and waste products
Digestive	mouth, esophagus, stomach, intestines	Digestion and absorption
Endocrine	all glands (thyroid, ovaries, pancreas)	Produce and release hormones
Immune	white blood cells, lymphatic tissue, marrow	Defend against foreign invaders
Integumentary	skin, nails, hair, sweat glands	Protective, body temperature regulation
Muscular	skeletal, smooth, and cardiac muscle	Body movement
Nervous	brain, spinal cord, nerves	Interprets and responds to stimuli
Reproductive	gonads, genitals	Reproduction and sexual characteristics
Respiratory	lungs, nose, mouth, throat, trachea	Gas exchange
Skeletal	bones, tendons, ligaments, joints	Structure and support
Urinary	kidneys, bladder, ureters	Waste excretion, water balance



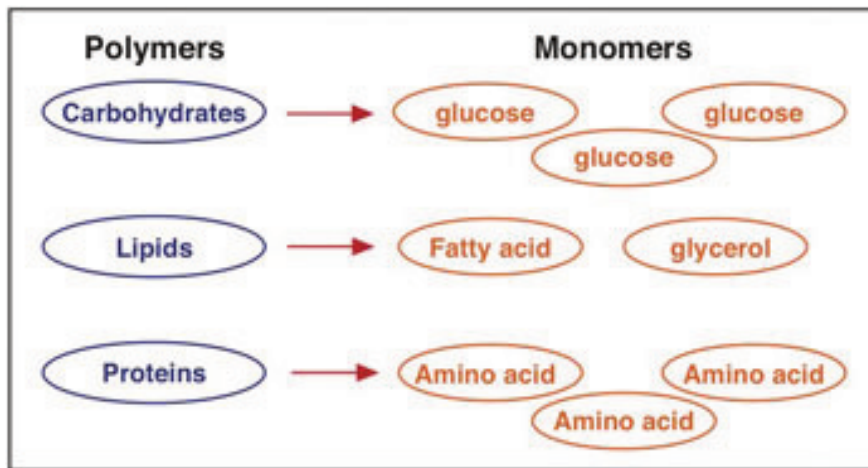
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The Digestive System

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

Once you have eaten, your digestive system (Figure 2.4 “The Human Digestive System”) starts the process that breaks down the components of food into smaller components that can be absorbed and taken into the body. To do this, the digestive system functions on two levels, mechanically to move and mix ingested food and chemically to break down large molecules. The smaller nutrient molecules can then be absorbed and processed by cells throughout the body for energy or used as building blocks for new cells. The digestive system is one of the eleven organ systems of the human body, and it is composed of several hollow tube-shaped organs including the mouth, pharynx, esophagus, stomach, small intestine, large intestine (colon), rectum, and anus. It is lined with mucosal tissue that secretes digestive juices (which aid in the breakdown of food) and mucus (which facilitates the propulsion of food through the tract). Smooth muscle tissue surrounds the digestive tract and its contraction produces waves, known as peristalsis, that propel food down the tract. Nutrients, as well as some non-nutrients, are absorbed. Substances such as fiber get left behind and are appropriately excreted.

Figure 2.4 Digestion Breakdown of Macronutrients



Digestion converts components of the food we eat into smaller molecules that can be absorbed into the body and utilized for energy needs or as building blocks for making larger molecules in cells.



Image by Gabriel Lee / CC BY-NC-SA

There has been significant talk about pre- and probiotic foods in the mainstream media. The World Health Organization defines probiotics as live bacteria that confer beneficial health effects on their host. They are sometimes called “friendly bacteria.” The most common bacteria labeled as probiotic is lactic acid bacteria (lactobacilli). They are added as live cultures to certain fermented foods such as yogurt. Prebiotics are indigestible foods, primarily soluble fibers, that stimulate the growth of certain strains of bacteria in the large intestine and provide health benefits to the host. A review article in the June 2008 issue of the *Journal of Nutrition* concludes that there is scientific consensus that probiotics ward off viral-induced diarrhea and reduce the symptoms of lactose intolerance.¹

Expert nutritionists agree that more health benefits of pre- and probiotics will likely reach scientific consensus. As the fields of pre- and probiotic manufacturing and their clinical study progress, more information on proper dosing and what exact strains of bacteria are potentially “friendly” will become available.

You may be interested in trying some of these foods in your diet. A simple food to try is kefir. Several websites

provide good recipes, including <http://www.kefir.net/recipes.htm>.

Kefir, a dairy product fermented with probiotic bacteria, can make a pleasant tasting milkshake.

Figure 2.5 The Human Digestive System

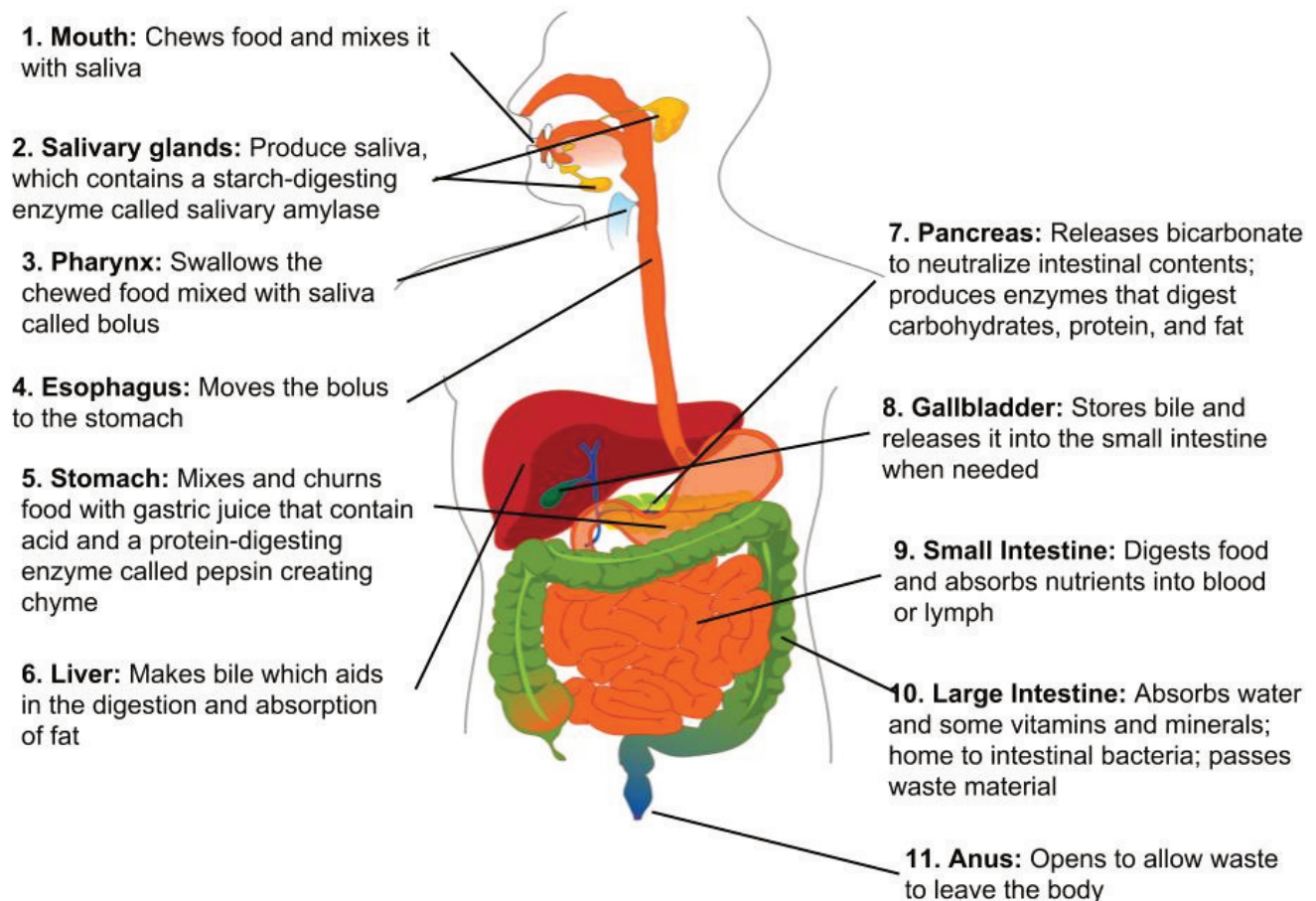


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FROM THE MOUTH TO THE STOMACH

There are four steps in the digestion process (Figure 2.5 “The Human Digestive System”). The first step is ingestion, which is the intake of food into the digestive tract. It may seem a simple process, but ingestion involves smelling food, thinking about food, and the involuntary release of saliva in the mouth to prepare for food entry. In the mouth, where the second step of digestion starts, the mechanical and chemical breakdown of food begins. The chemical breakdown of food involves enzymes, such as salivary amylase that starts the breakdown of large starch molecules into smaller components.

Mechanical breakdown starts with mastication (chewing) in the mouth. Teeth crush and grind large food particles, while saliva provides lubrication and enables food movement downward. The slippery mass of partially broken-down food is called a bolus, which moves down the digestive tract as you swallow. Swallowing may seem voluntary at first because it requires conscious effort to push the food with the tongue back toward the throat, but after this, swallowing proceeds involuntarily, meaning it cannot be stopped once it begins. As you swallow, the bolus is pushed from the mouth through the pharynx and into a muscular tube called the esophagus. As the bolus travels through the pharynx, a small flap called the epiglottis closes to prevent choking by keeping food from going into the trachea. Peristaltic contractions also known as peristalsis in the esophagus propel the food bolus down to the stomach (Figure 3.6 “Peristalsis in the Esophagus”). At the junction between the esophagus and stomach there is a sphincter muscle that remains closed until the food bolus approaches. The pressure of the food bolus stimulates the lower esophageal sphincter to relax and open and food then moves from the esophagus into the stomach. The mechanical breakdown of food is accentuated by the muscular contractions of the stomach and small intestine that mash, mix, slosh, and propel food down the alimentary canal. Solid food takes between four and eight seconds to travel down the esophagus, and liquids take about one second.

Figure 2.6 Peristalsis in the Esophagus

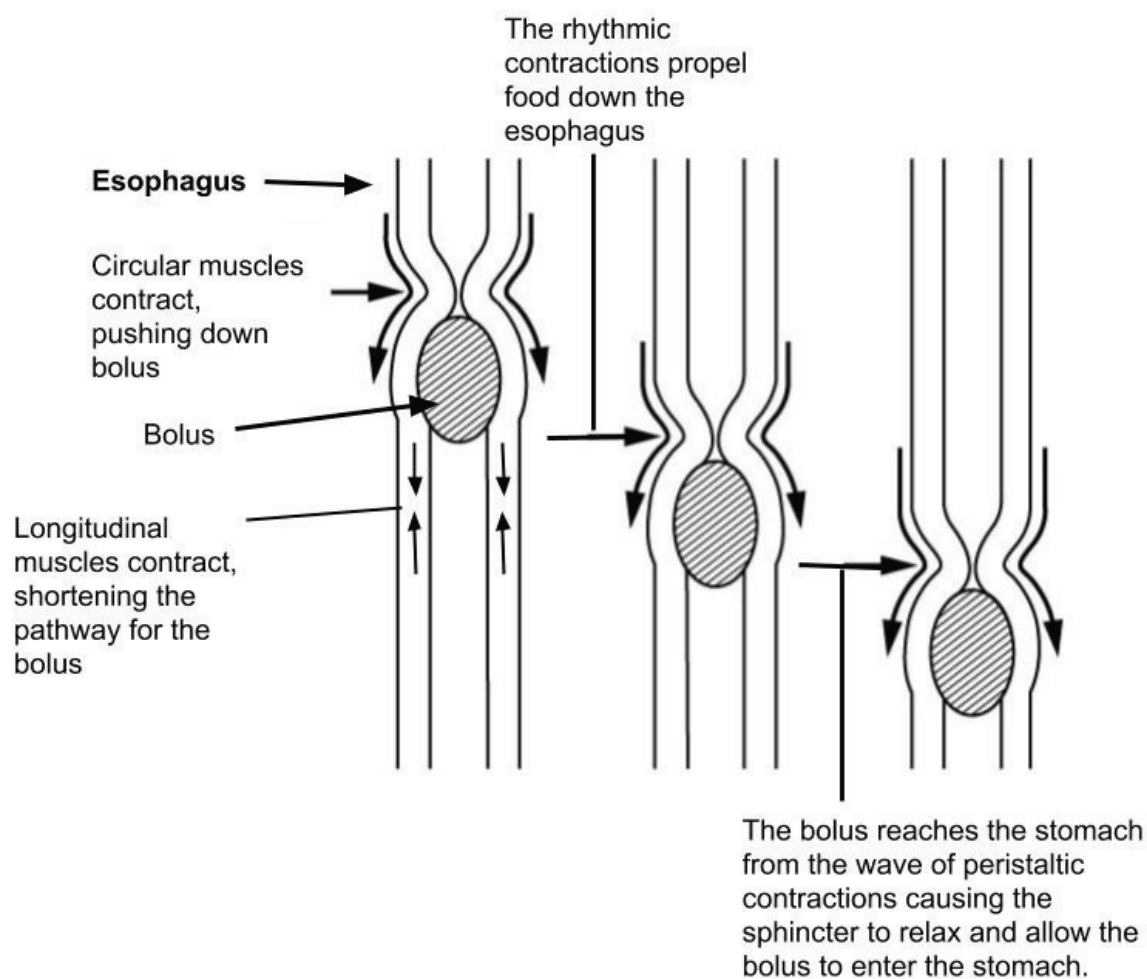


Image by Allison Calabrese / CC BY 4.0

FROM THE STOMACH TO THE SMALL INTESTINE

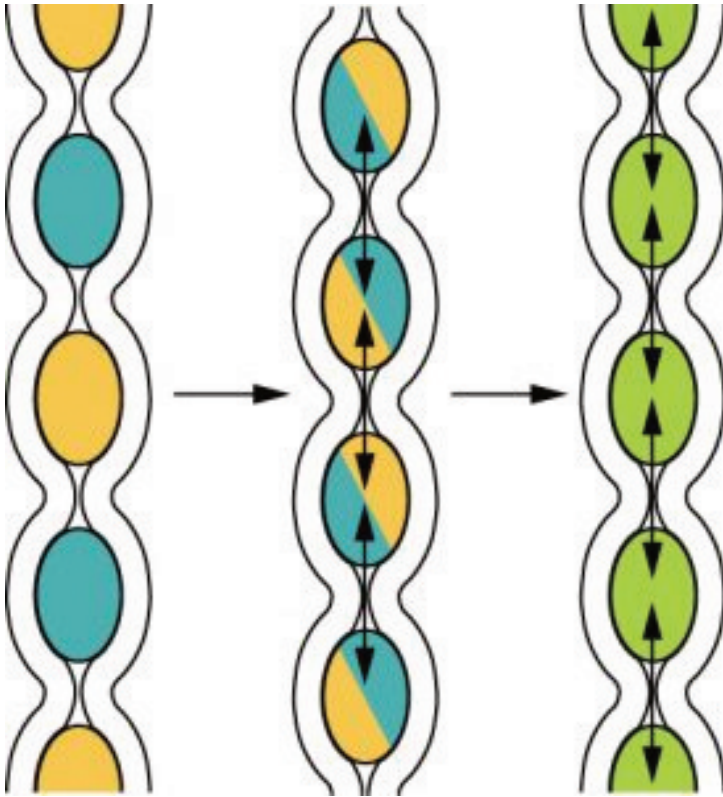
When food enters the stomach, a highly muscular organ, powerful peristaltic contractions help mash, pulverize, and churn food into chyme. Chyme is a semiliquid mass of partially digested food that also contains gastric juices secreted by cells in the stomach. These gastric juices contain hydrochloric acid and the enzyme pepsin, that chemically start breakdown of the protein components of food.

The length of time food spends in the stomach varies by the macronutrient composition of the meal. A high-fat or high-protein meal takes longer to break down than one rich in carbohydrates. It usually takes a few hours after a meal to empty the stomach contents completely into the small intestine.

The small intestine is divided into three structural parts: the duodenum, the jejunum, and the ileum. Once the chyme enters the duodenum (the first segment of the small intestine), the pancreas and gallbladder are stimulated and release juices that aid in digestion. The pancreas secretes up to 1.5 liters (.4 US gallons) of pancreatic juice through a duct into the duodenum per day. This fluid consists mostly of water, but it also contains bicarbonate ions that neutralize the acidity of the stomach-derived chyme and enzymes that further break down proteins, carbohydrates, and lipids. The gallbladder secretes a much smaller amount of a fluid called bile that helps to digest fats. Bile passes through a duct that joins the pancreatic ducts and is released into the duodenum. Bile is made in the liver and stored in the gall bladder. Bile's components act like detergents by surrounding fats similar to the way dish soap removes grease from a frying pan. This allows for the movement of fats in the watery environment of the small intestine. Two different types of muscular contractions, called peristalsis and segmentation, control the movement and mixing of the food in various stages of digestion through the small intestine.

Similar to what occurs in the esophagus and stomach, peristalsis is circular waves of smooth muscle contraction that propel food forward. Segmentation from circular muscle contraction slows movement in the small intestine by forming temporary “sausage link” type of segments that allows chyme to slosh food back and forth in both directions to promote mixing of the chyme and enhance absorption of nutrients (Figure 2.7 “Segmentation”). Almost all the components of food are completely broken down to their simplest units within the first 25 centimeters of the small intestine. Instead of proteins, carbohydrates, and lipids, the chyme now consists of amino acids, monosaccharides, and emulsified components of triglycerides.

Figure 2.7 Segmentation

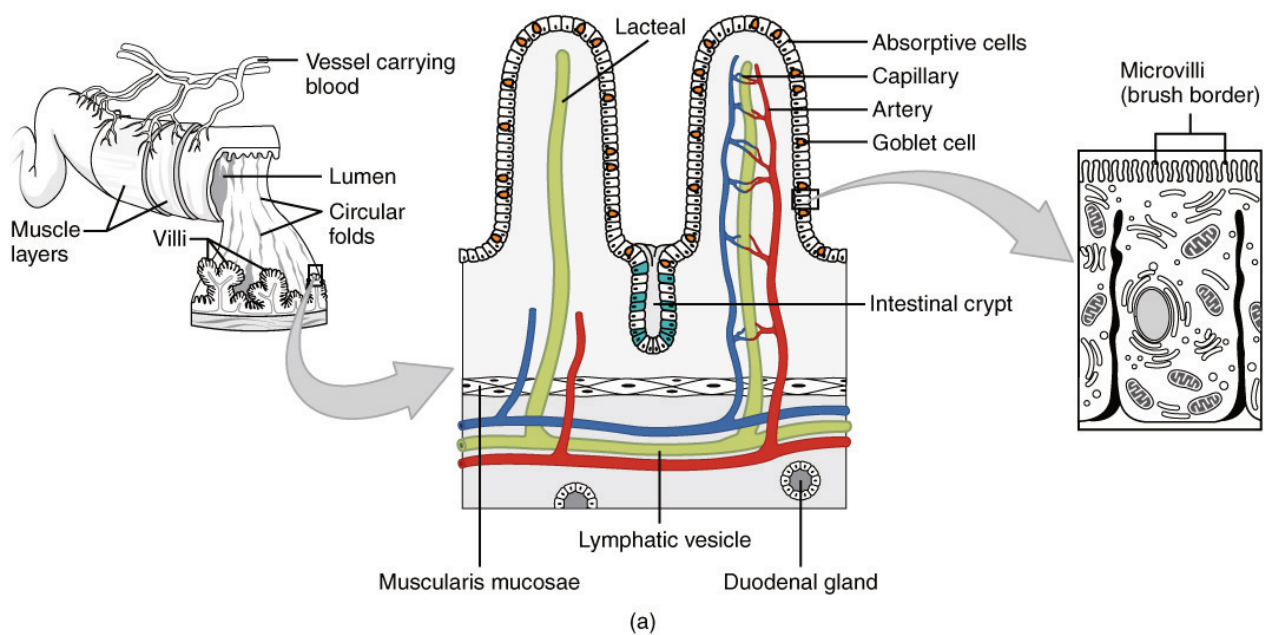


“Segmentation” by OpenStax College / CC BY 3.0

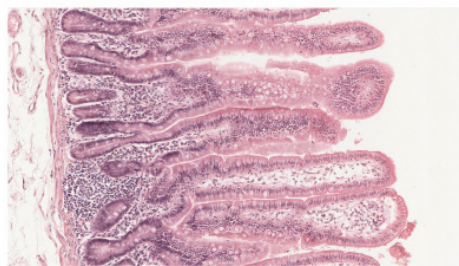
The third step of digestion (nutrient absorption) takes place mainly in the remaining length of the small intestine, or ileum (> 5 meters). The way the small intestine is structured gives it a huge surface area to maximize nutrient absorption. The surface area is increased by folds, villi, and microvilli. Digested nutrients are absorbed into either capillaries or lymphatic vessels contained within each microvillus.

The small intestine is perfectly structured for maximizing nutrient absorption. Its surface area is greater than 200 square meters, which is about the size of a tennis court. The large surface area is due to the multiple levels of folding. The internal tissue of the small intestine is covered in villi, which are tiny finger-like projections that are covered with even smaller projections, called microvilli (Figure 2.8 “Structure of the Small Intestine”). The digested nutrients pass through the absorptive cells of the intestine via diffusion or special transport proteins. Amino acids, short fatty acids, and monosaccharides (sugars) are transported from the intestinal cells into capillaries, but the larger fatty acids, fat-soluble vitamins, and other lipids are transported first through lymphatic vessels, which soon meet up with blood vessels.

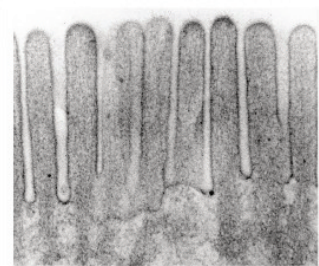
Figure 2.8 Structure of the Small Intestine



(b)



(c)



(d)

"Histology Small Intestines" by OpenStax College / CC BY 3.0

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 move from the small intestine to the large intestine (colon) through a connecting valve. A main task of the large intestine is to absorb much of the remaining water. Remember, water is present not only in solid foods and beverages, but also the stomach releases a few hundred milliliters of gastric juice, and the pancreas adds approximately 500 milliliters during the digestion of the meal. For the body to conserve water, it is important that excessive water is not lost in fecal matter. 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 intestinal tract. The number of bacteria residing in the large intestine is estimated to be greater than 10^{14} , which is more than the total number of cells in the human body (10^{13}). This may seem rather unpleasant, but the great majority of bacteria in the large intestine are harmless and many are even beneficial.

FROM THE LARGE INTESTINE TO THE ANUS

After a few hours in the stomach, plus three to six hours in the small intestine, and about sixteen hours in the large

intestine, the digestion process enters step four, which is the elimination of indigestible food matter as feces. Feces contain indigestible food components and gut bacteria (almost 50 percent of content). It is stored in the rectum until it is expelled through the anus via defecation.

NUTRIENTS ARE ESSENTIAL FOR CELL AND ORGAN FUNCTION

When the digestive system has broken down food to its nutrient components, the body eagerly awaits delivery. Water soluble nutrients absorbed into the blood travel directly to the liver via a major blood vessel called the portal vein. One of the liver's primary functions is to regulate metabolic homeostasis. Metabolic homeostasis is achieved when the nutrients consumed and absorbed match the energy required to carry out life's biological processes. Simply put, nutrient energy intake equals energy output. Whereas glucose and amino acids are directly transported from the small intestine to the liver, lipids are transported to the liver by a more circuitous route involving the lymphatic system. The lymphatic system is a one-way system of vessels that transports lymph, a fluid rich in white blood cells, and lipid soluble substances after a meal containing lipids. The lymphatic system slowly moves its contents through the lymphatic vessels and empties into blood vessels in the upper chest area. Now, the absorbed lipid soluble components are in the blood where they can be distributed throughout the body and utilized by cells (see Figure 2.9 "The Absorption of Nutrients").

Figure 2.9 The Absorption of Nutrients

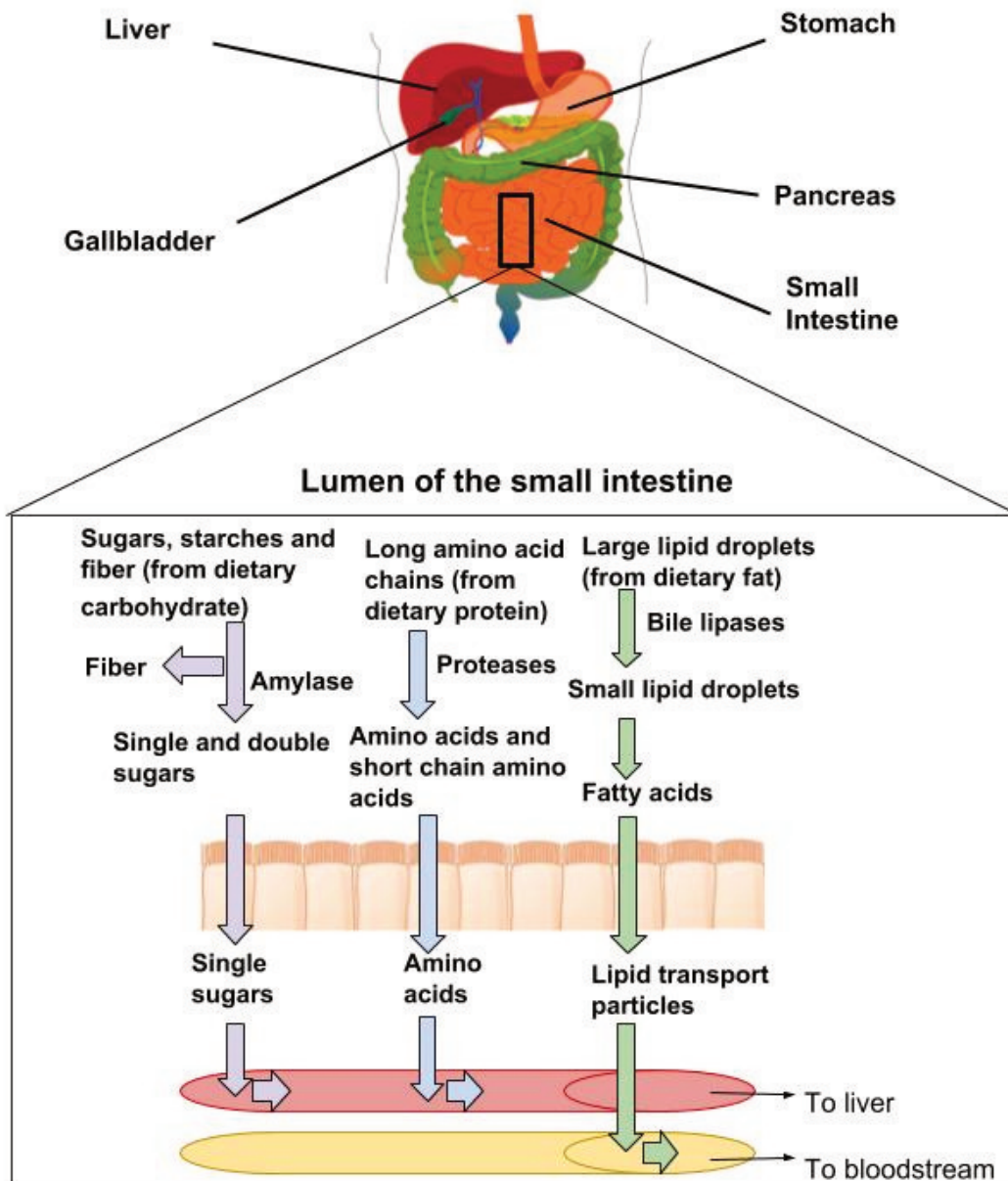


Image by Allison Calabrese / CC BY 4.0

Maintaining the body's energy status quo is crucial because when metabolic homeostasis is disturbed by an eating disorder or disease, bodily function suffers. This will be discussed in more depth in the last section of this chapter. The liver is the only organ in the human body that is capable of exporting nutrients for energy production to other tissues. Therefore, when a person is in between meals (fasted state) the liver exports nutrients, and when a person has just eaten (fed state) the liver stores nutrients within itself. Nutrient levels and the hormones that respond to their levels in the blood provide the input so that the liver can distinguish between the fasted and fed states and distribute

nutrients appropriately. Although not considered to be an organ, adipose tissue stores fat in the fed state and mobilizes fat components to supply energy to other parts of the body when energy is needed.

All eleven organ systems in the human body require nutrient input to perform their specific biological functions. Overall health and the ability to carry out all of life's basic processes is fueled by energy-supplying nutrients (carbohydrate, fat, and protein). Without them, organ systems would fail, humans would not reproduce, and the race would disappear. In this section, we will discuss some of the critical nutrients that support specific organ system functions.



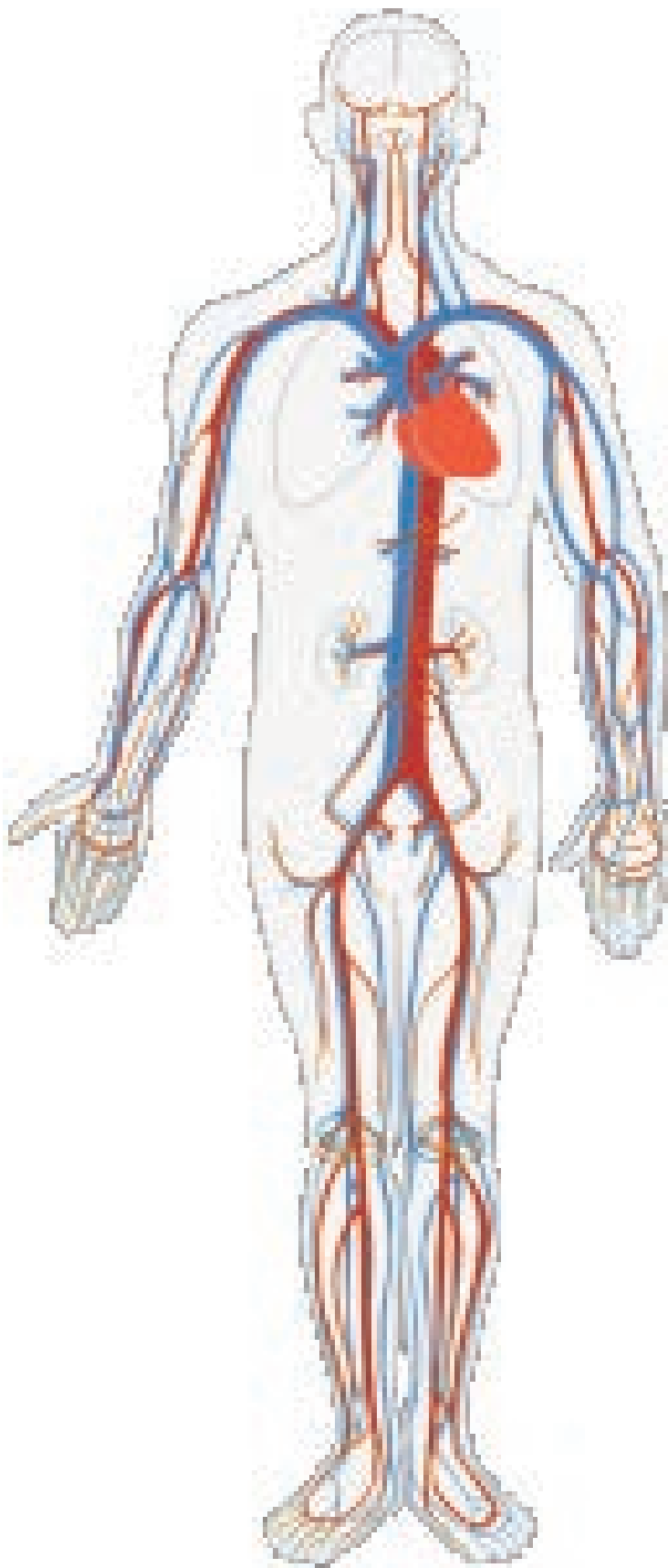
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Notes

1. Farnworth ER. The Evidence to Support Health Claims for Probiotics. J Nutr. 2008; 138(6), 1250S–4S. <http://jn.nutrition.org/content/138/6/1250S.long>. Accessed September 22, 2017.

The Cardiovascular System

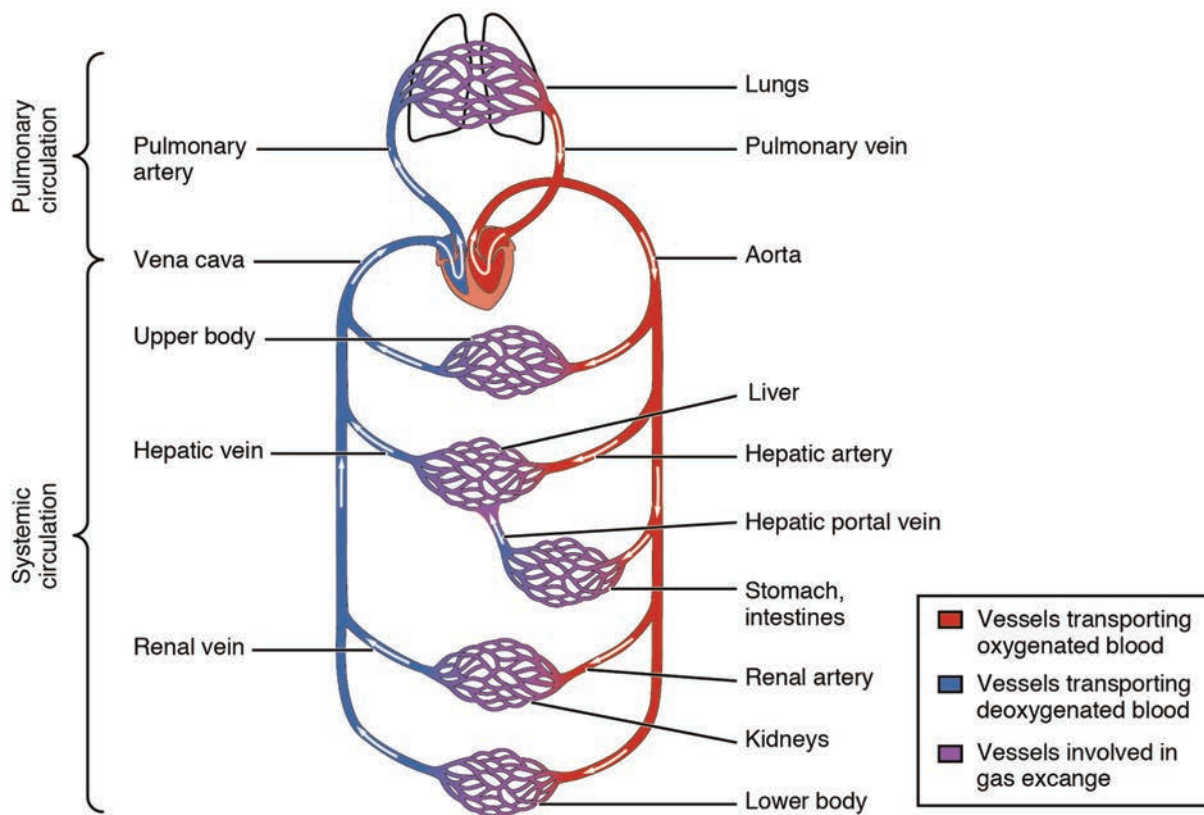
Figure 2.10 The Cardiovascular system



"Simplified diagram of the human Circulatory system in anterior view" by Mariana Ruiz / Public Domain

The cardiovascular system is one of the eleven organ systems of the human body. Its main function is to transport nutrients to cells and wastes from cells (Figure 2.12 "Cardiovascular Transportation of Nutrients"). This system consists of the heart, blood, and blood vessels. The heart pumps the blood, and the blood is the transportation fluid. The transportation route to all tissues, a highly intricate blood-vessel network, comprises arteries, veins, and capillaries. Nutrients absorbed in the small intestine travel mainly to the liver through the hepatic portal vein. From the liver, nutrients travel upward through the inferior vena cava blood vessel to the heart. The heart forcefully pumps the nutrient-rich blood first to the lungs to pick up some oxygen and then to all other cells in the body. Arteries become smaller and smaller on their way to cells, so that by the time blood reaches a cell, the artery's diameter is extremely small and the vessel is now called a capillary. The reduced diameter of the blood vessel substantially slows the speed of blood flow. This dramatic reduction in blood flow gives cells time to harvest the nutrients in blood and exchange metabolic wastes.

Figure 2.11 The Blood Flow in the Cardiovascular System



"Blood Flow Through the Heart" by OpenStax College / CC BY 3.0

BLOOD'S FUNCTION IN THE BODY AND IN METABOLISM SUPPORT

You know you cannot live without blood, and that your heart pumps your blood over a vast network of veins and arteries within your body, carrying oxygen to your cells. However, beyond these basic facts, what do you know about your blood?

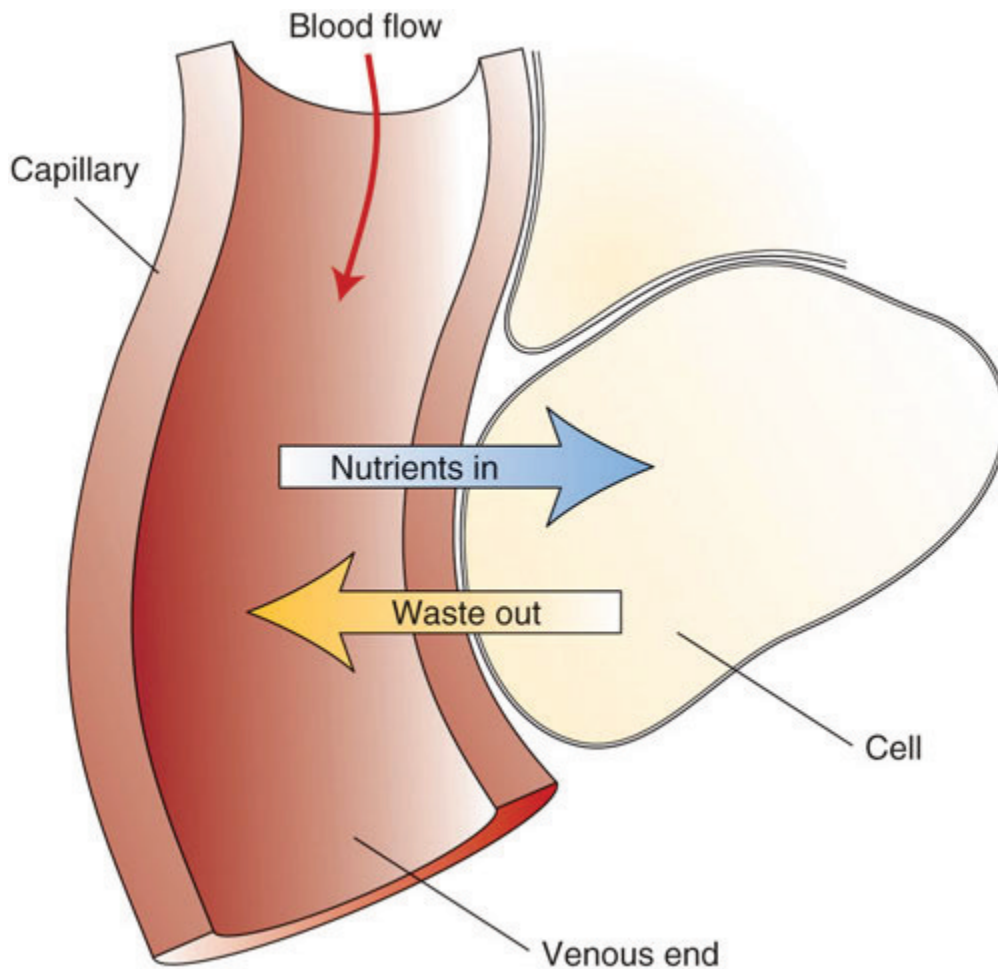
Blood transports absorbed nutrients to cells and waste products from cells. It supports cellular metabolism by transporting synthesized macromolecules from one cell type to another and carrying waste products away from cells. Additionally, it transports molecules, such as hormones, allowing for communication between organs. The volume of blood coursing throughout an adult human body is about 5 liters (1.3 US gallons) and accounts for approximately 8 percent of human body weight.

WHAT MAKES UP BLOOD AND HOW DO THESE SUBSTANCES SUPPORT BLOOD FUNCTION?

Blood is about 78 percent water and 22 percent solids by volume. The liquid part of blood is called plasma and it is mostly water (95 percent), but also contains proteins, ions, glucose, lipids, vitamins, minerals, waste products, gases, enzymes, and hormones. We have learned that the protein albumin is found in high concentrations in the blood. Albumin helps maintain fluid balance between blood and tissues, as well as helping to maintain a constant blood pH. We have also learned that the water component of blood is essential for its actions as a transport vehicle, and that the electrolytes carried in blood help to maintain fluid balance and a constant pH. Furthermore, the high water content of blood helps maintain body temperature, and the constant flow of blood distributes heat throughout the body. Blood is exceptionally good at temperature control, so much so that the many small blood vessels in your nose are capable of warming frigid air to body temperature before it reaches the lungs.

The cellular components of blood include red blood cells, white blood cells, and platelets. Red blood cells are the most numerous of the components. Each drop of blood contains millions of them. Red blood cells are red because they each contain approximately 270 million hemoglobin proteins, which contain the mineral iron, which turns red when bound to oxygen. The most vital duty of red blood cells is to transport oxygen from the lungs to all cells in the body so that cells can utilize oxygen to produce energy via aerobic metabolism. The white blood cells that circulate in blood are part of the immune system, and they survey the entire body looking for foreign invaders to destroy. They make up about 1 percent of blood volume. Platelets are fragments of cells that are always circulating in the blood in case of an emergency. When blood vessels are injured, platelets rush to the site of injury to plug the wound. Blood is under a constant state of renewal and is synthesized from stem cells residing in bone marrow. Red blood cells live for about 120 days, white blood cells live anywhere from eighteen hours to one year, or even longer, and platelets have a lifespan of about ten days.

Figure 2.12 Cardiovascular Transportation of Nutrients



The cardiovascular system transports nutrients to all cells and carries wastes out.

NUTRIENTS IN

Once absorbed from the small intestine, all nutrients require transport to cells in need of their support. Additionally, molecules manufactured in other cells sometimes require delivery to other organ systems. Blood is the conduit and blood vessels are the highway that support nutrient and molecule transport to all cells. Water-soluble molecules, such as some vitamins, minerals, sugars, and many proteins, move independently in blood. Fat-soluble vitamins, triglycerides, cholesterol, and other lipids are packaged into lipoproteins that allow for transport in the watery milieu of blood. Many proteins, drugs, and hormones are dependent on transport carriers, primarily by the plasma protein albumin. In addition to transporting all of these molecules, blood transfers oxygen taken in by the lungs to all cells in the body. As discussed, the iron-containing hemoglobin molecule in red blood cells serves as the oxygen carrier.

WASTES OUT

In the metabolism of macronutrients to energy, cells produce the waste products carbon dioxide and water. As blood travels through smaller and smaller vessels, the rate of blood flow is dramatically reduced, allowing for efficient exchange of nutrients and oxygen for cellular waste products through tiny capillaries. The kidneys remove any excess water from

the blood, and blood delivers the carbon dioxide to the lungs where it is exhaled. Also, the liver produces the waste product urea from the breakdown of amino acids and detoxifies many harmful substances, all of which require transport in the blood to the kidneys for excretion.

ALL FOR ONE, ONE FOR ALL

The eleven organ systems in the body completely depend on each other for continued survival as a complex organism. Blood allows for transport of nutrients, wastes, water, and heat, and is also a conduit of communication between organ systems. Blood's importance to the rest of the body is aptly presented in its role in glucose delivery, especially to the brain. The brain metabolizes, on average, 6 grams of glucose per hour. In order to avert confusion, coma, and death, glucose must be readily available to the brain at all times. To accomplish this task, cells in the pancreas sense glucose levels in the blood. If glucose levels are low, the hormone glucagon is released into the blood and is transported to the liver where it communicates the signal to ramp-up glycogen breakdown and glucose synthesis. The liver does just that, and glucose is released into the blood, which transports it to the brain. Concurrently, blood transports oxygen to support the metabolism of glucose to provide energy in the brain. Healthy blood conducts its duties rapidly, avoiding hypoglycemic coma and death. This is just one example of the body's survival mechanisms exemplifying life's mantra "All for one, one for all."

WHAT MAKES BLOOD HEALTHY?

Maintaining healthy blood, including its continuous renewal, is essential to support its vast array of vital functions. Blood is healthy when it contains the appropriate amount of water and cellular components and proper concentrations of dissolved substances, such as albumin and electrolytes. As with all other tissues, blood needs macro- and micronutrients to optimally function. In the bone marrow, where blood cells are made, amino acids are required to build the massive amount of hemoglobin packed within every red blood cell, along with all other enzymes and cellular organelles contained in each blood cell. Red blood cells, similar to the brain, use only glucose as fuel, and it must be in constant supply to support red-blood-cell metabolism. As with all other cells, the cells in the blood are surrounded by a plasma membrane, which is composed of mainly lipids. Blood health is also acutely sensitive to deficiencies in some vitamins and minerals more than others.

WHAT CAN BLOOD TESTS TELL YOU ABOUT YOUR HEALTH?

Figure 2.13 Blood Tests



Blood tests are helpful tools in diagnosing disease and provide much information on overall health. Image by Thirteen of Clubs / CC BY-SA

Since blood is the conduit of metabolic products and wastes, measuring the components of blood, and particular substances in blood, can reveal not only the health of blood, but also the health of other organ systems. In standard blood tests performed during an annual physical, the typical blood tests conducted can tell your physician about the functioning of a particular organ or about disease risk.

A biomarker is defined as a measurable molecule or trait that is connected with a specific disease or health condition. The concentrations of biomarkers in blood are indicative of disease risk. Some biomarkers are cholesterol, triglycerides, glucose, and prostate-specific antigen. The results of a blood test give the concentrations of substances in a person's blood and display the normal ranges for a certain population group. Many factors, such as physical activity level, diet, alcohol intake, and medicine intake can influence a person's blood-test levels and cause them to fall outside the normal range, so results of blood tests outside the "normal" range are not always indicative of health problems. The assessment of multiple blood parameters aids in the diagnosis of disease risk and is indicative of overall health status. See Table 2.2 "Blood Tests" for a partial list of substances measured in a typical blood test. This table notes only a few of the things that their levels tell us about health.

Table 2.2 Blood Tests

Substance Measured	Indicates
Red-blood-cell count	Oxygen-carrying capacity
Hematocrit (red-blood-cell volume)	Anemia risk
White-blood-cell count	Presence of infection
Platelet count	Bleeding disorders, atherosclerosis risk
pH	Metabolic, kidney, respiratory abnormalities
Albumin	Liver, kidney, and Crohn's disease, dehydration, protein deficiency
Bilirubin	Liver-function abnormality
Oxygen/Carbon Dioxide	Respiratory or metabolic abnormality
Hemoglobin	Oxygen-carrying capacity
Iron	Anemia risk
Magnesium	Magnesium deficiency
Electrolytes (calcium, chloride, magnesium, potassium)	Many illnesses (kidney, metabolic, etc.)
Cholesterol	Cardiovascular disease risk
Triglycerides	Cardiovascular disease risk
Glucose	Diabetes risk
Hormones	Many illnesses (diabetes, reproductive abnormalities)

National Heart Lung and Blood Institute. Types of Blood Tests.¹



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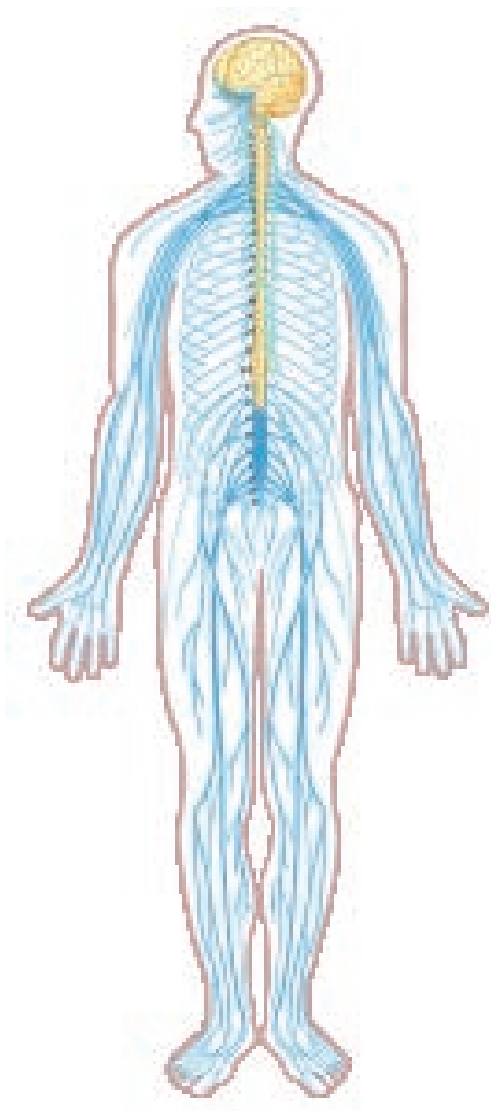
Notes

1. <http://www.nhlbi.nih.gov/health/health-topics/topics/bdt/types.html>. Published January 6, 2012. Accessed September 22, 2017.

Central Nervous System

The human brain (which weighs only about 3 pounds, or 1,300 kilograms) is estimated to contain over one hundred billion neurons. Neurons form the core of the central nervous system, which consists of the brain, spinal cord, and other nerve bundles in the body. The main function of the central nervous system is to sense changes in the external environment and create a reaction to them. For instance, if your finger comes into contact with a thorn on a rose bush, a sensory neuron transmits a signal from your finger up through the spinal cord and into the brain. Another neuron in the brain sends a signal that travels back to the muscles in your hand and stimulates muscles to contract and you jerk your finger away. All of this happens within a tenth of a second. All nerve impulses travel by the movement of charged sodium, potassium, calcium, and chloride atoms. Nerves communicate with each other via chemicals built from amino acids called neurotransmitters. Eating adequate protein from a variety of sources will ensure the body gets all of the different amino acids that are important for central nervous system function.

Figure 2.14 The Central Nervous System



Nervous System” by William Crochot / CC BY-SA 4.0

The brain's main fuel is glucose and only in extreme starvation will it use anything else. For acute mental alertness and clear thinking, glucose must be systematically delivered to the brain. This does not mean that sucking down a can of sugary soda before your next exam is a good thing. Just as too much glucose is bad for other organs, such as the kidneys and pancreas, it also produces negative effects upon the brain. Excessive glucose levels in the blood can cause a loss of cognitive function, and chronically high blood-glucose levels can damage brain cells. The brain's cognitive functions include language processing, learning, perceiving, and thinking. Recent scientific studies demonstrate that having continuously high blood-glucose levels substantially elevates the risk for developing Alzheimer's disease, which is the greatest cause of age-related cognitive decline.

The good news is that much research is directed toward determining the best diets and foods that slow cognitive decline and maximize brain health. A study in the June 2010 issue of the *Archives of Neurology* reports that people over age 65 who adhered to diets that consisted of higher intakes of nuts, fish, poultry, tomatoes, cruciferous vegetables, fruits, salad

dressing, and dark green, and leafy vegetables, as well as a lower intake of high-fat dairy products, red meat, organ meat, and butter, had a much reduced risk for Alzheimer's disease.¹

Other scientific studies provide supporting evidence that foods rich in omega-3 fatty acids and/or antioxidants provide the brain with protection against Alzheimer's disease. One potential "brain food" is the blueberry. The protective effects of blueberries upon the brain are linked to their high content of anthocyanins, which are potent antioxidants and reduce inflammation. A small study published in the April 2010 issue of the Journal of Agricultural and Food Chemistry found that elderly people who consumed blueberry juice every day for twelve weeks had improved learning and memorization skills in comparison to other subjects given a placebo drink.²

However, it is important to keep in mind that this was a short-term study. Blueberries also are high in manganese, and high intake of manganese over time is known to have neurotoxic effects. Variety in the diet is perhaps the most important concept in applied nutrition. More clinical trials are evaluating the effects of blueberries and other foods that benefit the brain and preserve its function as we age.



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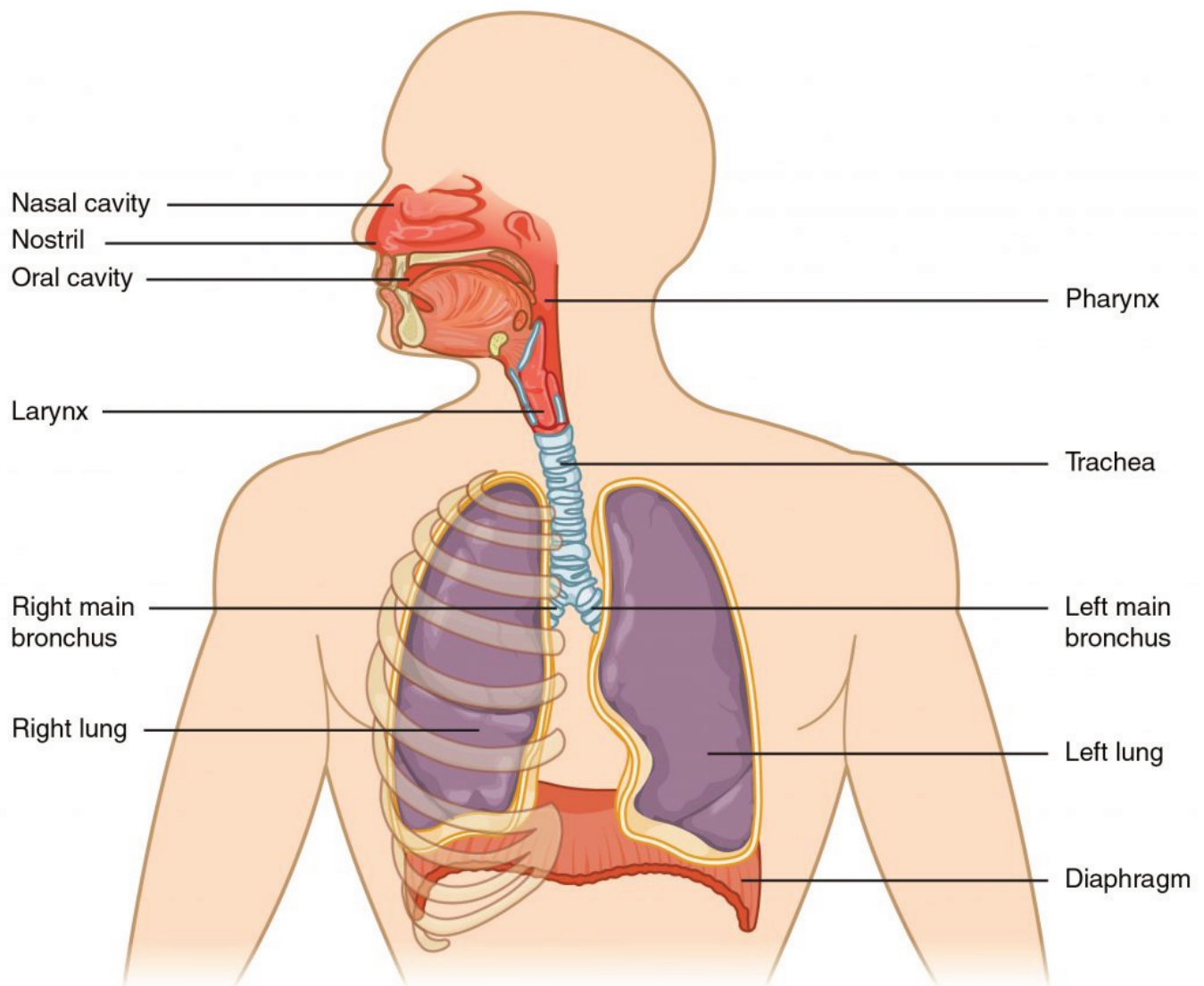
1. Gu Y, Nieves JW, et al. Food Combination and Alzheimer Disease Risk: A Protective Diet. Arch Neurol. 2010; 67(6), 699–706. <https://www.ncbi.nlm.nih.gov/pubmed/20385883>. Accessed September 22, 2017.
2. Krikorian R, Shidler MD, et al. Blueberry Supplementation Improves Memory in Older Adults. J Agric Food Chem. 2010; 58(7). <https://www.ncbi.nlm.nih.gov/pubmed/20047325>. Accessed September 22, 2017.

The Respiratory System

A typical human cannot survive without breathing for more than 3 minutes, and even if you wanted to hold your breath longer, your autonomic nervous system would take control. This is because cells need to maintain oxidative metabolism for energy production that continuously regenerates adenosine triphosphate (ATP). For oxidative phosphorylation to occur, oxygen is used as a reactant and carbon dioxide is released as a waste product. You may be surprised to learn that although oxygen is a critical need for cells, it is actually the accumulation of carbon dioxide that primarily drives your need to breathe. Carbon dioxide is exhaled and oxygen is inhaled through the respiratory system, which includes muscles to move air into and out of the lungs, passageways through which air moves, and microscopic gas exchange surfaces covered by capillaries. The cardiovascular system transports gases from the lungs to tissues throughout the body and vice versa. A variety of diseases can affect the respiratory system, such as asthma, emphysema, chronic obstructive pulmonary disorder (COPD), and lung cancer. All of these conditions affect the gas exchange process and result in labored breathing and other difficulties.

The major organs of the respiratory system function primarily to provide oxygen to body tissues for cellular respiration, remove the waste product carbon dioxide, and help to maintain acid-base balance. Portions of the respiratory system are also used for non-vital functions, such as sensing odors, producing speech, and for straining, such as during childbirth or coughing.

Figure 2.15 Major Respiratory Structures



The major respiratory structures span the nasal cavity to the diaphragm. Functionally, the respiratory system can be divided into a conducting zone and a respiratory zone. The conducting zone of the respiratory system includes the organs and structures not directly involved in gas exchange (trachea and bronchi). The gas exchange occurs in the respiratory zone.

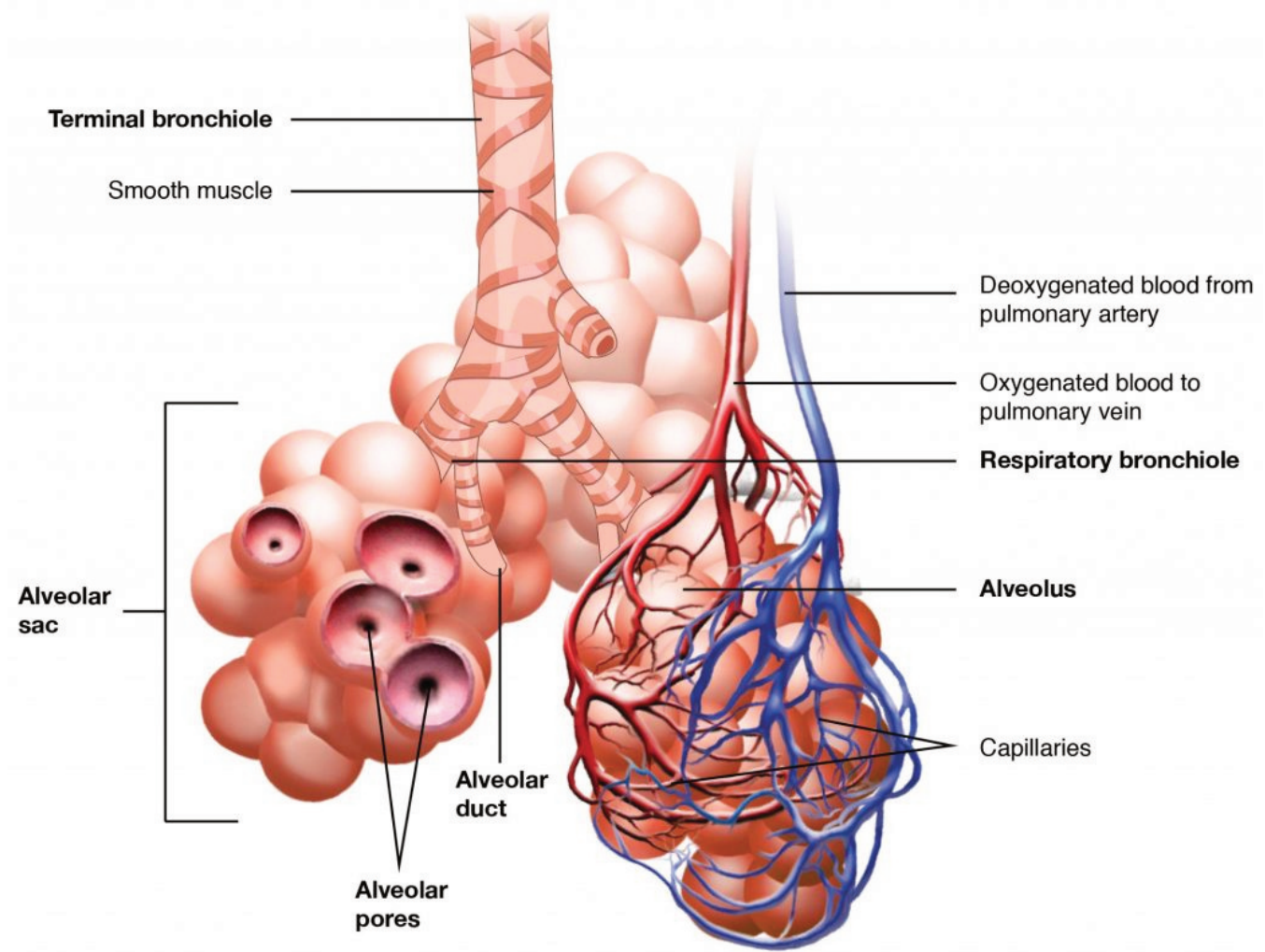
CONDUCTING ZONE

The major functions of the conducting zone are to provide a route for incoming and outgoing air, remove debris and pathogens from the incoming air, and warm and humidify the incoming air. Several structures within the conducting zone perform other functions as well. The epithelium of the nasal passages, for example, is essential to sensing odors, and the bronchial epithelium that lines the lungs can metabolize some airborne carcinogens. The conducting zone includes the nose and its adjacent structures, the pharynx, the larynx, the trachea, and the bronchi.

RESPIRATORY ZONE

In contrast to the conducting zone, the respiratory zone includes structures that are directly involved in gas exchange. The respiratory zone begins where the terminal bronchioles join a respiratory bronchiole, the smallest type of bronchiole (Figure 2.16 “Respiratory Zone”), which then leads to an alveolar duct, opening into a cluster of alveoli.

Figure 2.16 Respiratory Zone



Bronchioles lead to alveolar sacs in the respiratory zone, where gas exchange occurs.

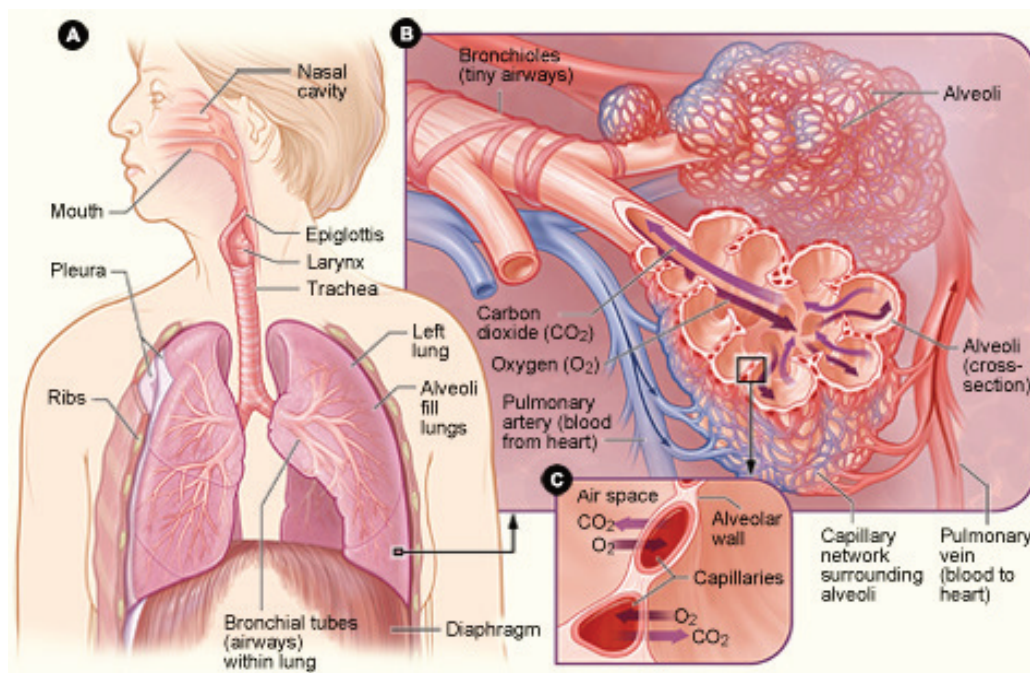
Alveoli

An alveolar duct is a tube composed of smooth muscle and connective tissue, which opens into a cluster of alveoli. An alveolus is one of the many small, grape-like sacs that are attached to the alveolar ducts.

An alveolar sac is a cluster of many individual alveoli that are responsible for gas exchange. An alveolus is approximately 200 μm in diameter with elastic walls that allow the alveolus to stretch during air intake, which greatly increases the

surface area available for gas exchange. Alveoli are connected to their neighbors by alveolar pores, which help maintain equal air pressure throughout the alveoli and lung.

Figure 2.17 Location of Respiratory System



“Human Respiratory System” by United States National Institute of Health: National Heart, Lung and Blood Institute / Public Domain

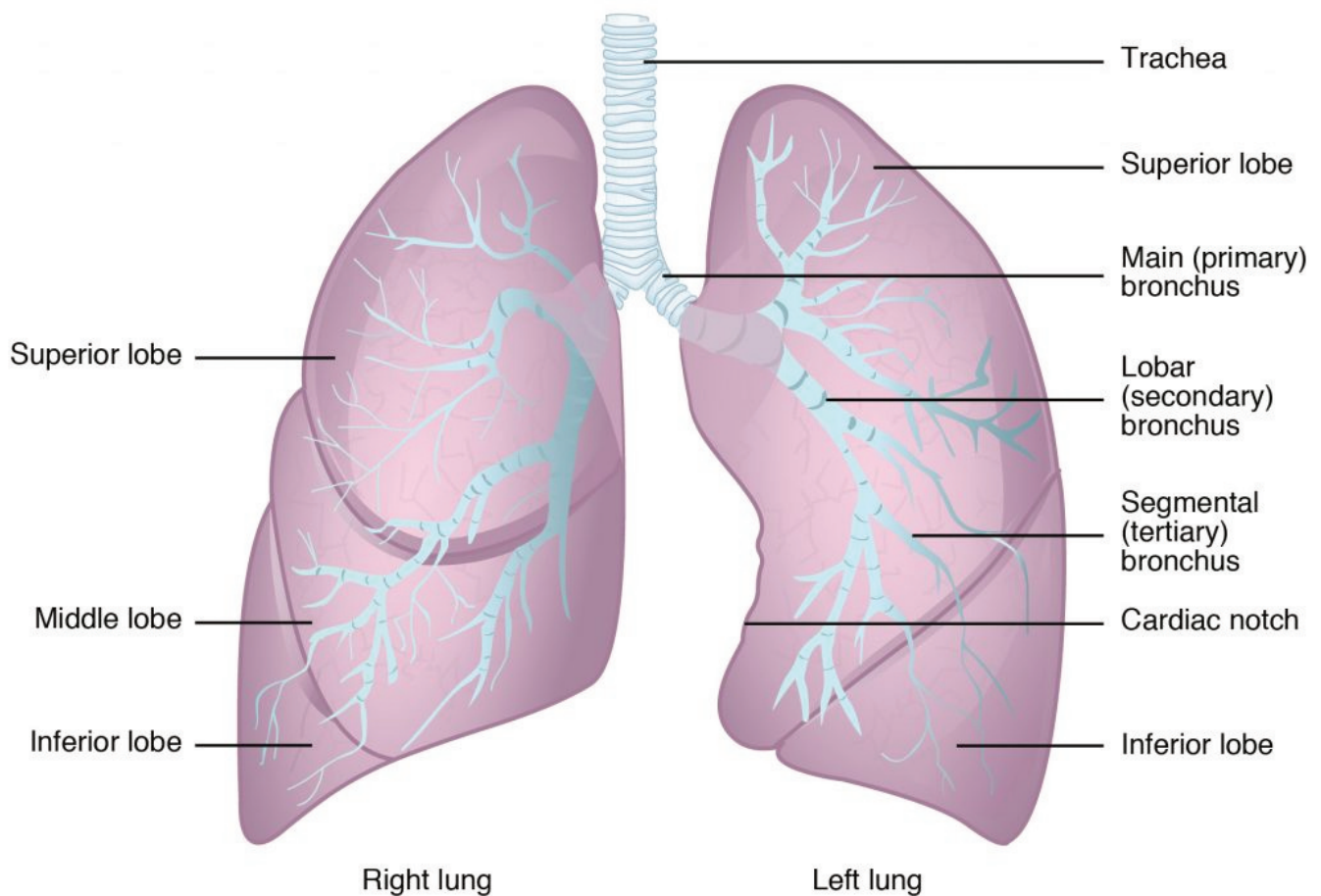
Figure 2.17 shows the location of the respiratory structures in the body. Figure B is an enlarged view of the airways, alveoli (air sacs), and capillaries (tiny blood vessels). Figure C is a close-up view of gas exchange between the capillaries and alveoli. CO₂ is carbon dioxide, and O₂ is oxygen.

A major organ of the respiratory system, each lung houses structures of both the conducting and respiratory zones. The main function of the lungs is to perform the exchange of oxygen and carbon dioxide with air from the atmosphere. To this end, the lungs exchange respiratory gases across a very large epithelial surface area—about 70 square meters—that is highly permeable to gases.

GROSS ANATOMY OF THE LUNGS

The lungs are pyramid-shaped, paired organs that are connected to the trachea by the right and left bronchi; below the lungs is the diaphragm, a flat, dome-shaped muscle located at the base of the lungs and thoracic cavity.

Figure 2.18 Basic Anatomy of the Lungs



Each lung is composed of smaller units called lobes. Fissures separate these lobes from each other. The right lung consists of three lobes: the superior, middle, and inferior lobes. The left lung consists of two lobes: the superior and inferior lobes.

BLOOD SUPPLY

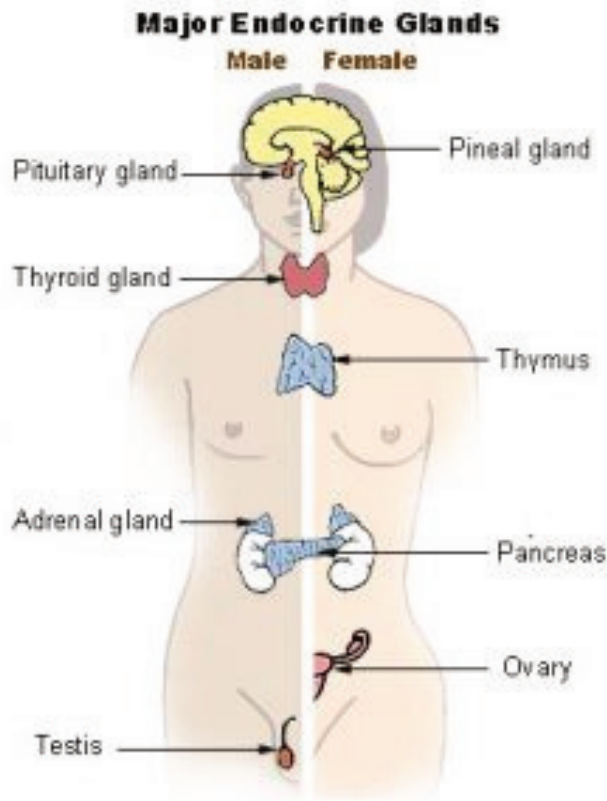
The major function of the lungs is to perform gas exchange, which requires blood flowing through the lung tissues (the pulmonary circulation). This blood supply contains deoxygenated blood and travels to the lungs where erythrocytes, also known as red blood cells, pick up oxygen to be transported to tissues throughout the body. The pulmonary artery carries deoxygenated blood to the lungs. The pulmonary artery branches multiple times as it follows the bronchi, and each branch becomes progressively smaller in diameter down to the tiny capillaries where the alveoli release carbon dioxide from blood into the lungs to be exhaled and take up oxygen from inhaled air to oxygenate the blood. Once the blood is oxygenated, it drains from the alveoli by way of multiple pulmonary veins that exit the lungs to carry oxygen to the rest of the body.



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The Endocrine System

Figure 2.19 The Endocrine System



"Major Endocrine Glands" by National Cancer Institute / Public Domain

The functions of the endocrine system are intricately connected to the body's nutrition. This organ system is responsible for regulating appetite, nutrient absorption, nutrient storage, and nutrient usage, in addition to other functions, such as reproduction. The glands in the endocrine system are the pituitary, thyroid, parathyroid, adrenals, thymus, pineal, pancreas, ovaries, and testes. The glands secrete hormones, which are biological molecules that regulate cellular processes in other target tissues, so they require transportation by the circulatory system. Adequate nutrition is critical for the functioning of all the glands in the endocrine system. A protein deficiency impairs gonadal-hormone release, preventing reproduction. Athletic teenage girls with very little body fat often do not menstruate. Children who are malnourished usually do not produce enough growth hormone and fail to reach normal height for their age group. Probably the most popularized connection between nutrition and the functions of the endocrine system is that unhealthy dietary patterns are linked to obesity and the development of Type 2 diabetes. The Centers for Disease Control and Prevention (CDC) estimates that twenty-six million Americans have Type 2 diabetes as of 2011. This is 8.3 percent of the US population. Counties with the highest incidence of obesity also have the highest incidence of Type 2 diabetes. To see

how the rise in obesity in this country is paralleled by the rise in Type 2 diabetes, review this report by the CDC.
https://www.cdc.gov/diabetes/statistics/slides/maps_diabetesobesity_trends.pdf

What is the causal relationship between overnutrition and Type 2 diabetes? The prevailing theory is that the overconsumption of high-fat and high-sugar foods causes changes in muscle, fat, and liver cells that leads to a diminished response from the pancreatic hormone insulin. These cells are called “insulin-resistant.” Insulin is released after a meal and instructs the liver and other tissues to take up glucose and fatty acids that are circulating in the blood. When cells are resistant to insulin they do not take up enough glucose and fatty acids, so glucose and fatty acids remain at high concentrations in the blood. The chronic elevation of glucose and fatty acids in the blood also causes damage to other tissues over time, so that people who have Type 2 diabetes are at increased risk for cardiovascular disease, kidney disease, nerve damage, and eye disease.

Career Connection

Do your part to slow the rising tide of obesity and Type 2 diabetes in this country. On the individual level, improve your own family’s diet; at the local community level, support the development of more nutritious school lunch programs; and at the national level, support your nation’s nutrition goals. Visit the CDC Diabetes Public Health Resource website at <https://www.cdc.gov/diabetes/>. It provides information on education resources, projects, and programs, and spotlights news on diabetes. For helpful information on obesity, visit <https://www.cdc.gov/obesity/>. The CDC also has workplace web-based resources with the mission of designing work sites that prevent obesity. See <https://www.cdc.gov/workplacehealthpromotion/index.html> or more details.



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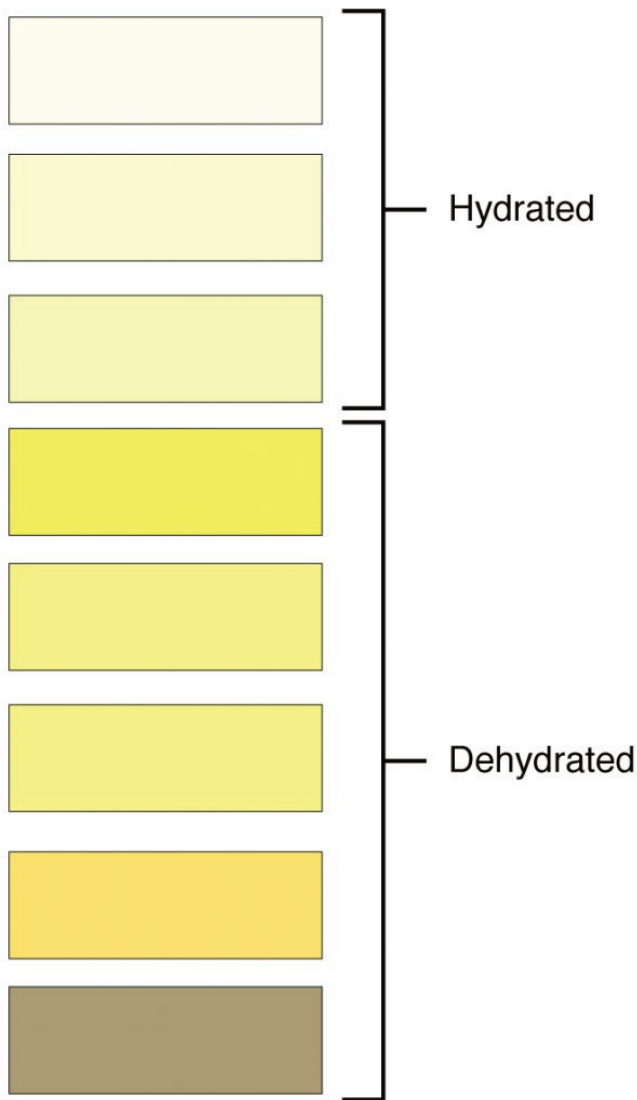
The Urinary System

The urinary system has roles you may be well aware of: cleansing the blood and ridding the body of wastes probably come to mind. However, there are additional, equally important functions played by the system. Take for example, regulation of pH, a function shared with the lungs and the buffers in the blood. Additionally, the regulation of blood pressure is a role shared with the heart and blood vessels. What about regulating the concentration of solutes in the blood? Did you know that the kidney is important in determining the concentration of red blood cells? Eighty-five percent of the erythropoietin (EPO) produced to stimulate red blood cell production is produced in the kidneys. The kidneys also perform the final synthesis step of vitamin D production, converting calcidiol to calcitriol, the active form of vitamin D.

If the kidneys fail, these functions are compromised or lost altogether, with devastating effects on homeostasis. The affected individual might experience weakness, lethargy, shortness of breath, anemia, widespread edema (swelling), metabolic acidosis, rising potassium levels, heart arrhythmias, and more. Each of these functions is vital to your well-being and survival. The urinary system, controlled by the nervous system, also stores urine until a convenient time for disposal and then provides the anatomical structures to transport this waste liquid to the outside of the body. Failure of nervous control or the anatomical structures leading to a loss of control of urination results in a condition called incontinence.

Characteristics of the urine change, depending on influences such as water intake, exercise, environmental temperature, nutrient intake, and other factors. Some of the characteristics such as color and odor are rough descriptors of your state of hydration. For example, if you exercise or work outside, and sweat a great deal, your urine will turn darker and produce a slight odor, even if you drink plenty of water. Athletes are often advised to consume water until their urine is clear. This is good advice; however, it takes time for the kidneys to process body fluids and store it in the bladder. Another way of looking at this is that the quality of the urine produced is an average over the time it takes to make that urine. Producing clear urine may take only a few minutes if you are drinking a lot of water or several hours if you are working outside and not drinking much.

Figure 2.20 Urine Color



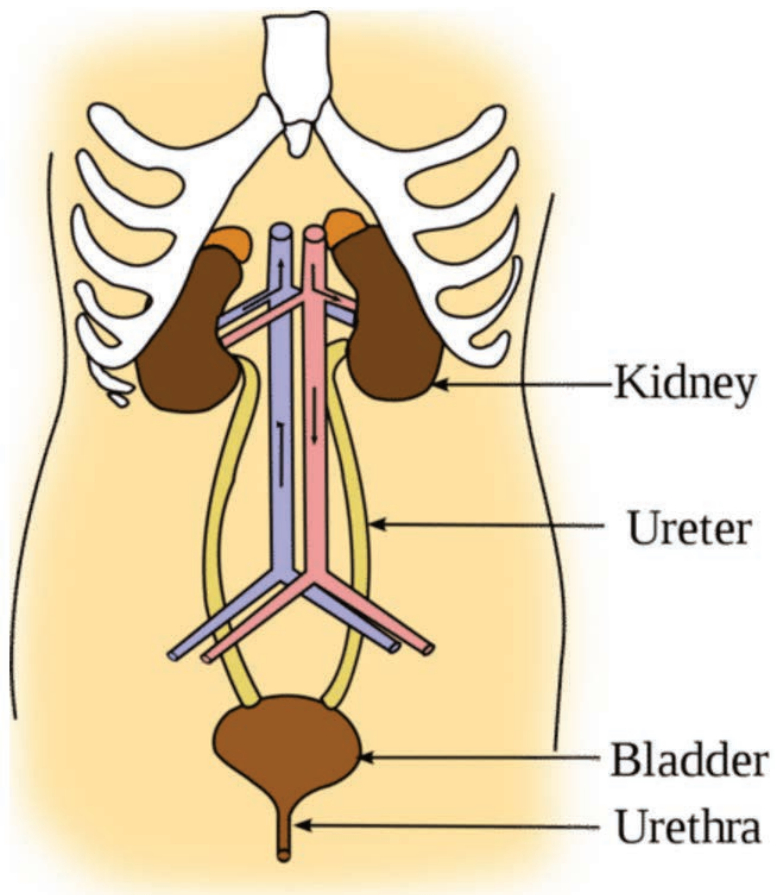
"Urine Color" by OpenStax College / CC BY 3.0

Urine volume varies considerably. The normal range is one to two liters per day. The kidneys must produce a minimum urine volume of about 500 mL/day to rid the body of wastes. Output below this level may be caused by severe dehydration or renal disease and is termed oliguria. The virtual absence of urine production is termed anuria. Excessive urine production is polyuria, which may occur in diabetes mellitus when blood glucose levels exceed the filtration capacity of the kidneys and glucose appears in the urine. The osmotic nature of glucose attracts water, leading to increased water loss in the urine.

Urine is a fluid of variable composition that requires specialized structures to remove it from the body safely and efficiently. Blood is filtered, and the filtrate is transformed into urine at a relatively constant rate throughout the day. This processed liquid is stored until a convenient time for excretion. All structures involved in the transport and storage of the urine are large enough to be visible to the naked eye. This transport and storage system not only stores the waste, but it protects the tissues from damage due to the wide range of pH and osmolarity of the urine, prevents infection

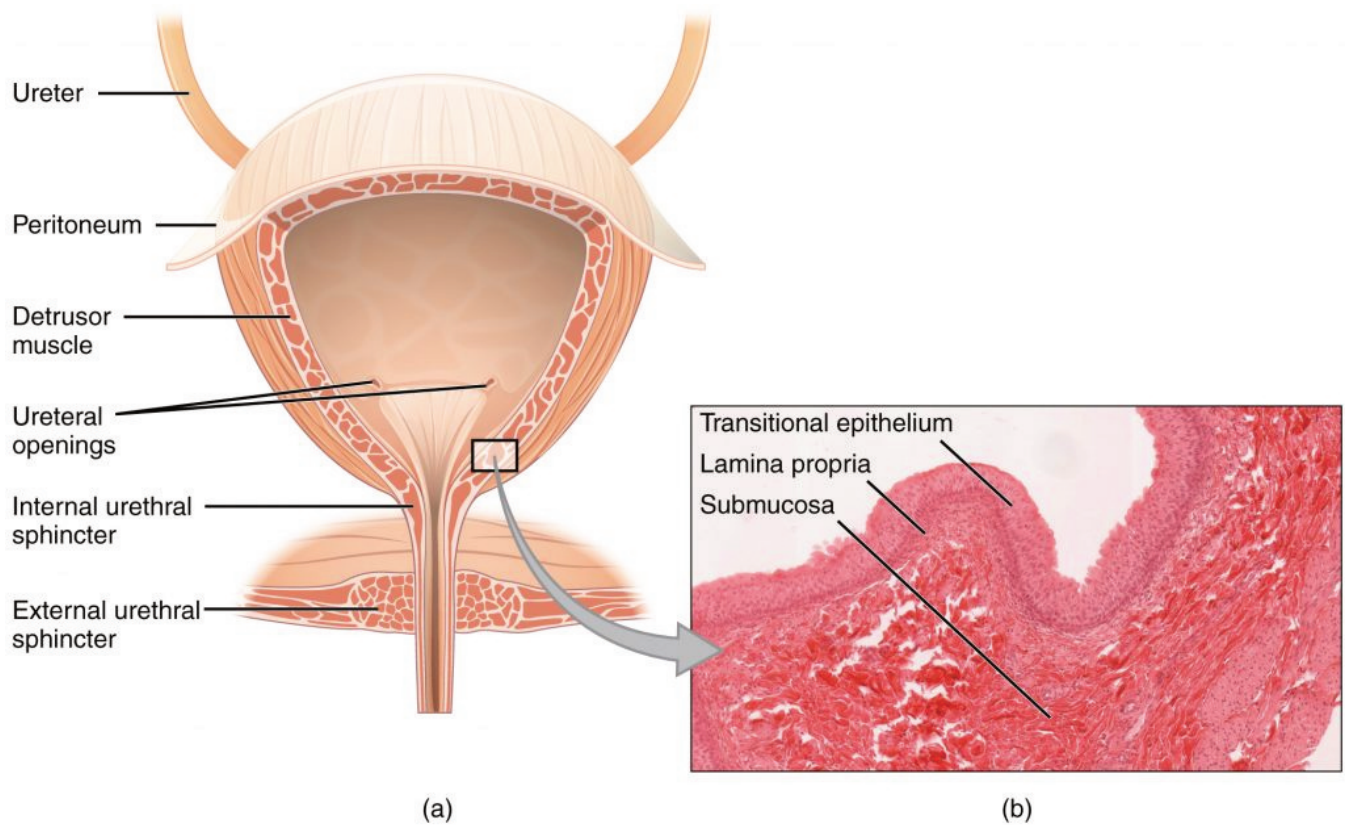
by foreign organisms, and for the male, provides reproductive functions. The urinary bladder collects urine from both ureters (Figure 2.21 “Urinary System Location”).

Figure 2.21 Urinary System Location



“Illu Urinary System” by Thstehle / Public Domain

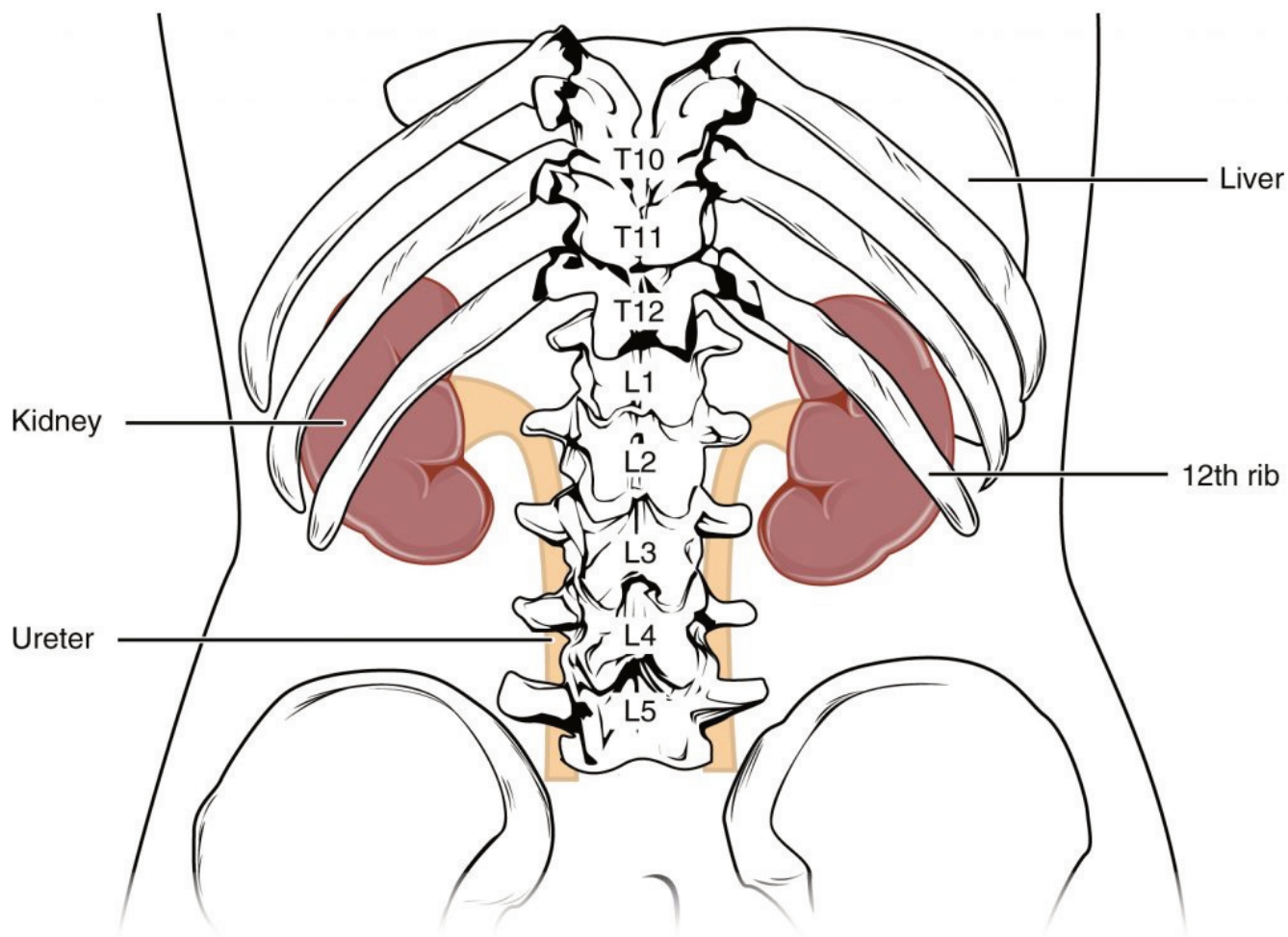
Figure 2.22 The Bladder



"The Bladder" by OpenStax College / CC BY 3.0

The kidneys lie on either side of the spine in the retroperitoneal space behind the main body cavity that contains the intestines. The kidneys are well protected by muscle, fat, and the lower ribs. They are roughly the size of your fist, and the male kidney is typically a bit larger than the female kidney. The kidneys are well vascularized, receiving about 25 percent of the cardiac output at rest.

Figure 2.23 The Kidneys



"Kidney Position in Abdomen" by OpenStax College / CC BY 3.0

The kidneys (as viewed from the back of the body) are slightly protected by the ribs and are surrounded by fat for protection (not shown).

The effects of failure of parts of the urinary system may range from inconvenient (incontinence) to fatal (loss of filtration and many other functions). The kidneys catalyze the final reaction in the synthesis of active vitamin D that in turn helps regulate Ca^{++} . The kidney hormone EPO stimulates erythrocyte development and promotes adequate O_2 transport. The kidneys help regulate blood pressure through Na^+ and water retention and loss. The kidneys work with the adrenal cortex, lungs, and liver in the renin-angiotensin-aldosterone system to regulate blood pressure. They regulate osmolarity of the blood by regulating both solutes and water. Three electrolytes are more closely regulated than others: Na^+ , Ca^{++} , and K^+ . The kidneys share pH regulation with the lungs and plasma buffers, so that proteins can preserve their three-dimensional conformation and thus their function.



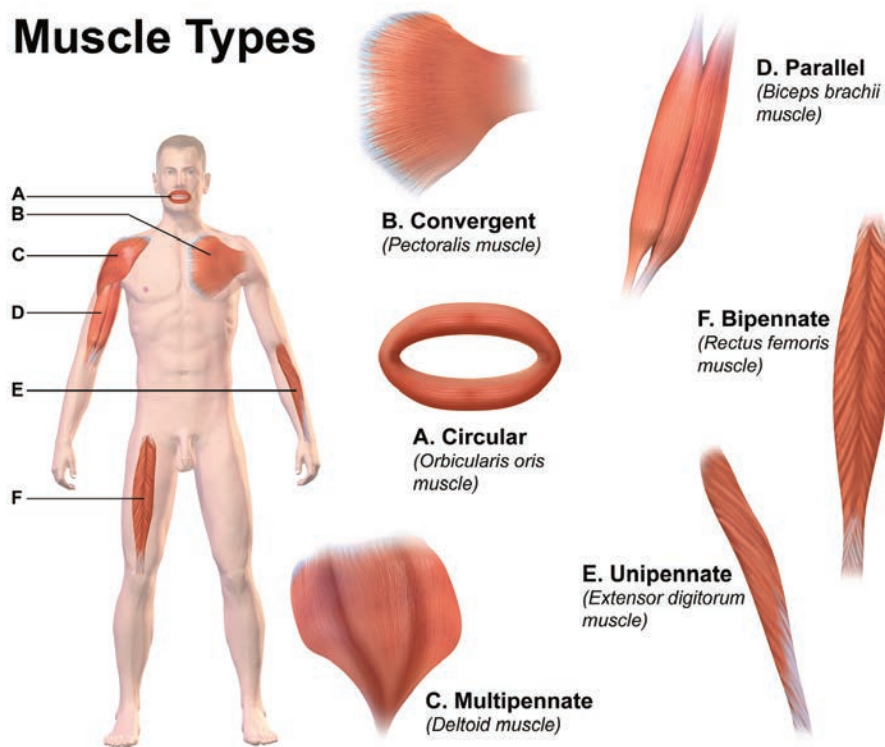
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The Muscular System

The muscular system allows the body to move voluntarily, but it also controls involuntary movements of other organ systems such as heartbeat in the circulatory system and peristaltic waves in the digestive system. It consists of over six hundred skeletal muscles, as well as the heart muscle, the smooth muscles that surround your entire alimentary canal, and all your arterial blood vessels (see Figure 2.24 “The Muscular System in the Human Body”). Muscle contraction relies on energy delivery to the muscle. Each movement uses up cellular energy, and without an adequate energy supply, muscle function suffers. Muscle, like the liver, can store the energy from glucose in the large polymeric molecule glycogen. But unlike the liver, muscles use up all of their own stored energy and do not export it to other organs in the body. Muscle is not as susceptible to low levels of blood glucose as the brain because it will readily use alternate fuels such as fatty acids and protein to produce cellular energy.

Figure 2.24 The Muscular System in the Human Body

Muscle Types



“Muscle Types” by BruceBlaus / CC BY-SA 4.0



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The Skeletal System

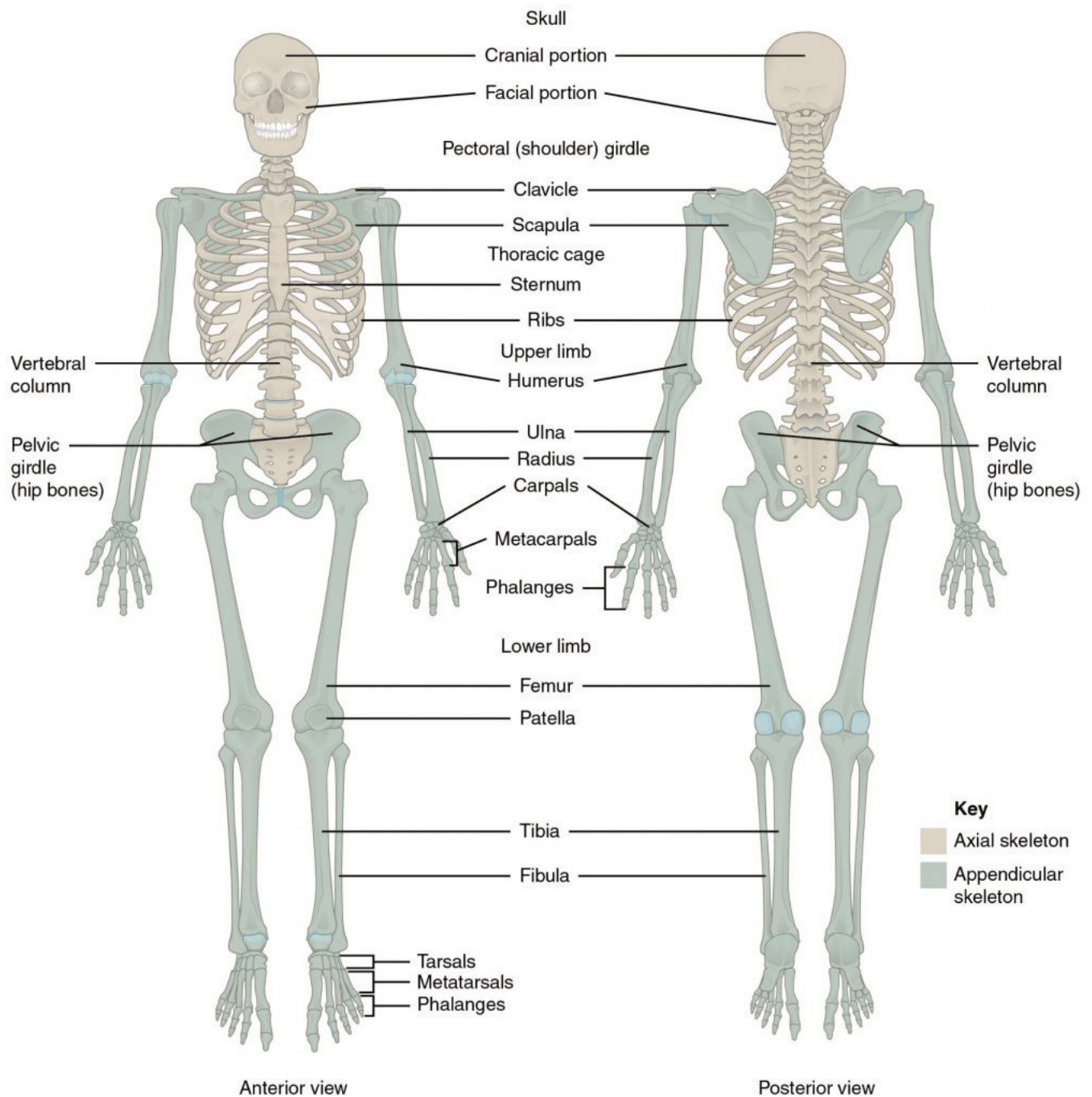
BONE STRUCTURE AND FUNCTION

Your bones are stronger than reinforced concrete. Bone tissue is a composite of fibrous strands of collagen (a type of protein) that resemble the steel rebar in concrete and a hardened mineralized matrix that contains large amounts of calcium, just like concrete. But this is where the similarities end. Bone outperforms reinforced concrete by several orders of magnitude in compression and tension strength tests. Why? The microarchitecture of bone is complex and built to withstand extreme forces. Moreover, bone is a living tissue that is continuously breaking down and forming new bone to adapt to mechanical stresses.

WHY IS THE SKELETAL SYSTEM IMPORTANT?

The human skeleton consists of 206 bones and other connective tissues called ligaments, tendons, and cartilage. Ligaments connect bones to other bones, tendons connect bones to muscles, and cartilage provides bones with more flexibility and acts as a cushion in the joints between bones. The skeleton's many bones and connective tissues allow for multiple types of movement such as typing and running. The skeleton provides structural support and protection for all the other organ systems in the body. The skull, or cranium, is like a helmet and protects the eyes, ears, and brain. The ribs form a cage that surrounds and protects the lungs and heart. In addition to aiding in movement, protecting organs, and providing structural support, red and white blood cells and platelets are synthesized in bone marrow. Another vital function of bones is that they act as a storage depot for minerals such as calcium, phosphorous, and magnesium. Although bone tissue may look inactive at first glance, at the microscopic level you will find that bones are continuously breaking down and reforming. Bones also contain a complex network of canals, blood vessels, and nerves that allow for nutrient transport and communication with other organ systems.

Figure 2.25 Human Skeletal Structure



“Axial Skeleton” by Openstax College / CC BY 3.0

The human skeleton contains 206 bones. It is divided into two main parts, the axial and appendicular.

BONE ANATOMY AND STRUCTURE

To optimize bone health through nutrition, it is important to understand bone anatomy. The skeleton is composed of two

main parts, the axial and the appendicular parts. The axial skeleton consists of the skull, vertebral column, and rib cage, and is composed of eighty bones. The appendicular skeleton consists of the shoulder girdle, pelvic girdle, and upper and lower extremities, and is composed of 126 bones. Bones are also categorized by size and shape. There are four types of bone: long bones, short bones, flat bones, and irregular bones. The longest bone in your body is the femur (thigh bone), which extends from your hip to your knee. It is a long bone and functions to support your weight as you stand, walk, or run. Your wrist is composed of eight irregular-shaped bones, which allow for the intricate movements of your hands. Your twelve ribs on each side of your body are curved flat bones that protect your heart and lungs. Thus, the bones' different sizes and shapes allow for their different functions.

Bones are composed of approximately 65 percent inorganic material known as mineralized matrix. This mineralized matrix consists of mostly crystallized hydroxyapatite. The bone's hard crystal matrix of bone tissue gives it its rigid structure. The other 35 percent of bone is organic material, most of which is the fibrous protein collagen. The collagen fibers are networked throughout bone tissue and provide it with flexibility and strength. The bones' inorganic and organic materials are structured into two different tissue types. There is spongy bone, also called trabecular or cancellous bone, and compact bone, also called cortical bone (Figure 2.26 "The Arrangement of Bone Tissues"). The two tissue types differ in their microarchitecture and porosity. Trabecular bone is 50 to 90 percent porous and appears as a lattice-like structure under the microscope. It is found at the ends of long bones, in the cores of vertebrae, and in the pelvis. Trabecular bone tissue makes up about 20 percent of the adult skeleton. The more dense cortical bone is about 10 percent porous and it looks like many concentric circles, similar to the rings in a tree trunk, sandwiched together (Figure 2.27 "Cortical (Compact) Bone"). Cortical bone tissue makes up approximately 80 percent of the adult skeleton. It surrounds all trabecular tissue and is the only bone tissue in the shafts of long bones.

Figure 2.26 The Arrangement of Bone Tissues

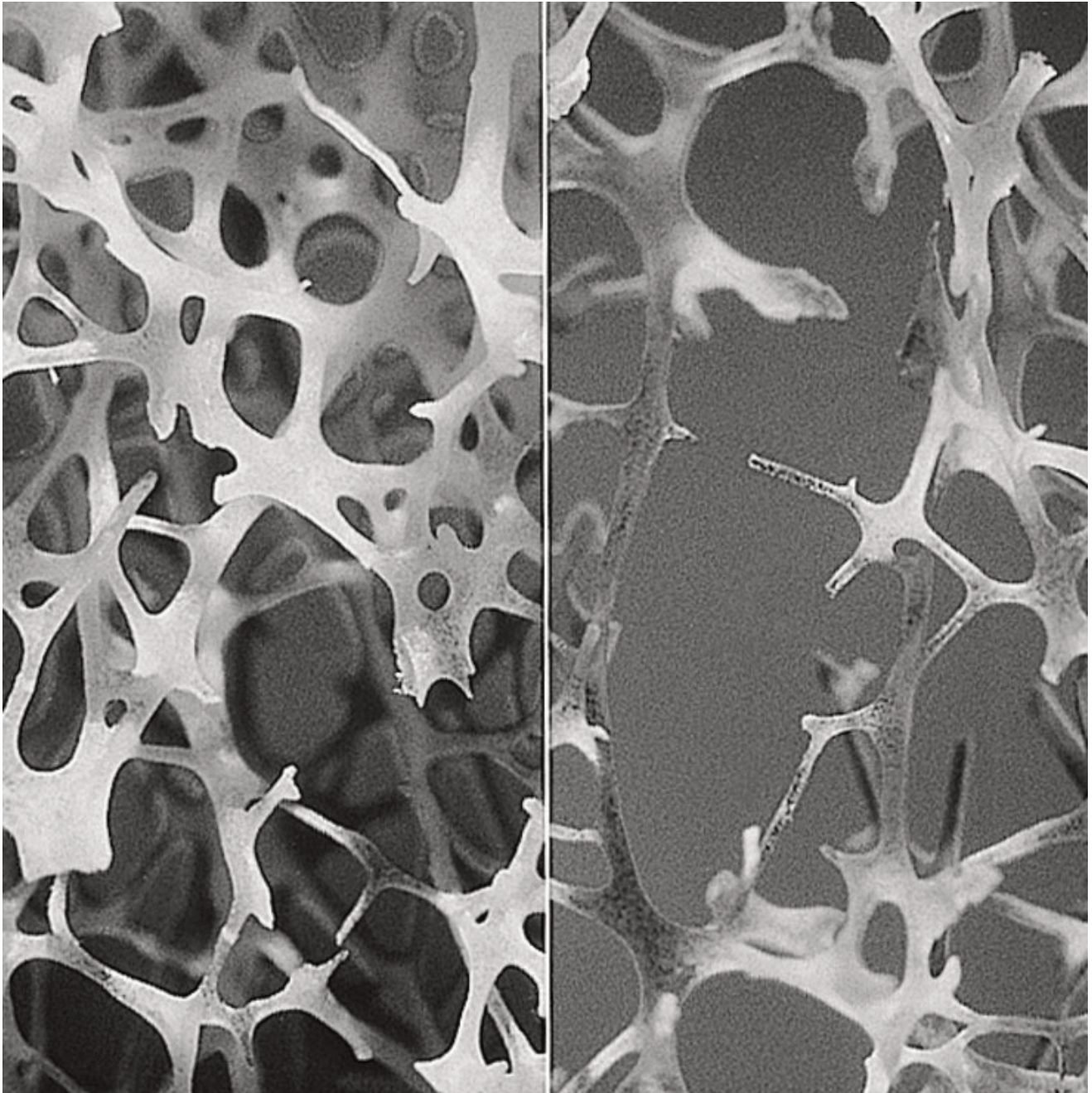
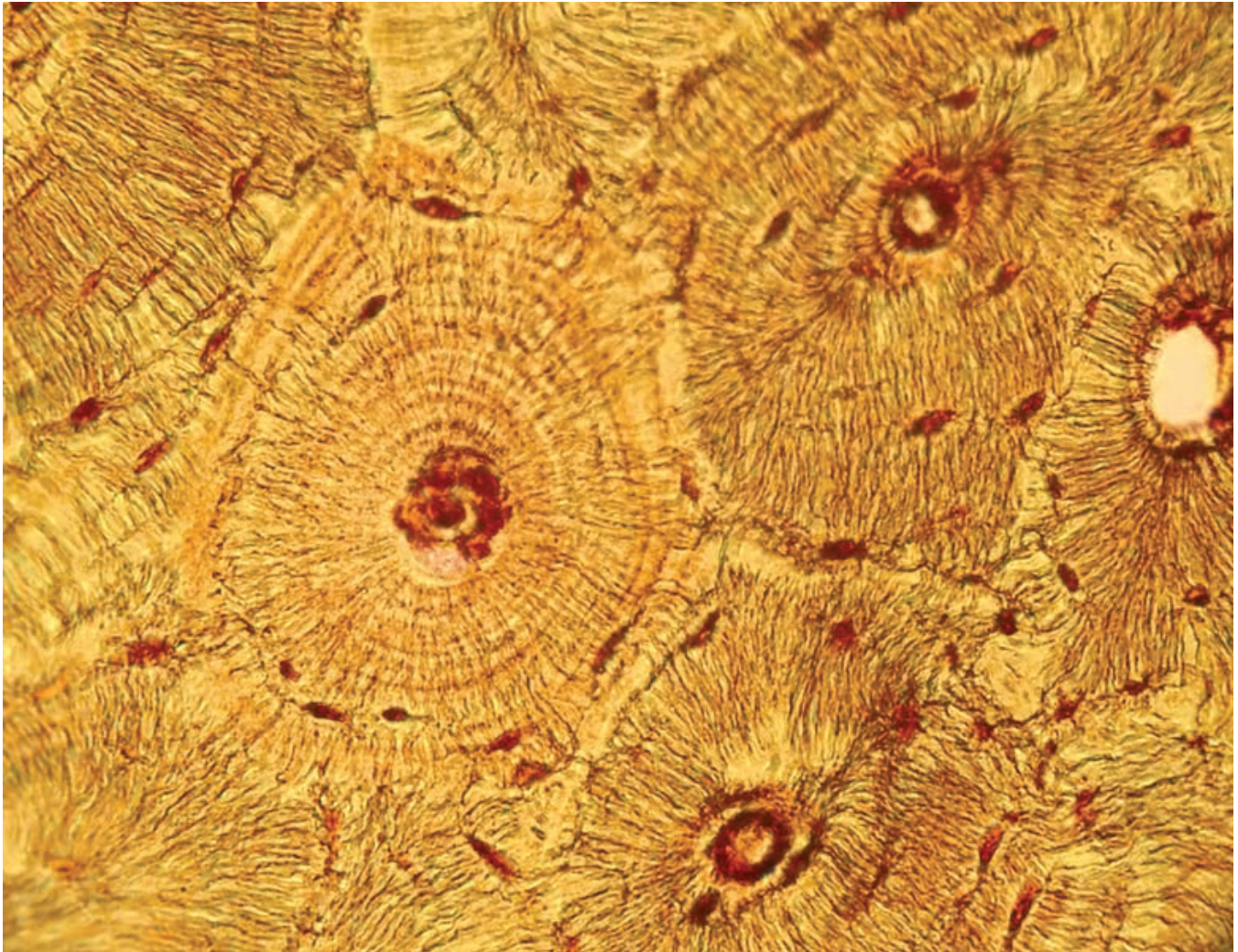


Image by Gtirouflet / CC BY-SA 3.0

The two basic tissue types of bones are trabecular and cortical. This photo shows normal (left) and degraded (right) trabecular (spongy) bone.

Figure 2.27 Cortical (Compact) Bone.



"Compact Bone with osteons" by Lord of Konrad / CC0

Bone tissue is arranged in an organized manner. A thin membrane, called the periosteum, surrounds the bone. It contains connective tissue with many blood vessels and nerves. Lying below the periosteum is the cortical bone. In some bones, the cortical bone surrounds the less-dense trabecular bone and the bone marrow lies within the trabecular bone, but not all bones contain trabecular tissue or marrow.

BONE TISSUES AND CELLS, MODELING AND REMODELING

Bone tissue contains many different cell types that constantly resize and reshape bones throughout growth and adulthood. Bone tissue cells include osteoprogenitor cells, osteoblasts, osteoclasts, and osteocytes. The osteoprogenitor cells are cells that have not matured yet. Once they are stimulated, some will become osteoblasts, the bone builders, and others will become osteoclasts, the cells that break bone down. Osteocytes are the most abundant cells in bone tissue. Osteocytes are star-shaped cells that are networked throughout the bone via their long cytoplasmic arms that allow for the exchange of nutrients and other factors from bones to the blood and lymph.

BONE MODELING AND REMODELING

During infancy, childhood, and adolescence, bones are continuously growing and changing shape through two processes called growth (ossification) and modeling. In fact, in the first year of life, almost 100 percent of the bone tissue in the skeleton is replaced. In the process of modeling, bone tissue is dismantled at one site and built up at a different site. In adulthood, our bones stop growing and modeling, but continue to go through a process of bone remodeling. In the process of remodeling, bone tissue is degraded and built up at the same location. About 10 percent of bone tissue is remodeled each year in adults. Bones adapt their structure to the forces acting upon them, even in adulthood. This phenomenon is called Wolff's law, which states that bones will develop a structure that is best able to resist the forces acting upon them. This is why exercising, especially when it involves weight-bearing activities, increases bone strength.

The first step in bone remodeling is osteocyte activation. Osteocytes detect changes in mechanical forces, calcium homeostasis, or hormone levels. In the second step, osteoclasts are recruited to the site of the degradation. Osteoclasts are large cells with a highly irregular ruffled membrane. These cells fuse tightly to the bone and secrete hydrogen ions, which acidify the local environment and dissolve the minerals in the bone tissue matrix. This process is called bone resorption and resembles pit excavation. Our bodies excavate pits in our bone tissue because bones act as storehouses for calcium and other minerals. Bones supply these minerals to other body tissues as the demand arises. Bone tissue also remodels when it breaks so that it can repair itself. Moreover, if you decide to train to run a marathon your bones will restructure themselves by remodeling to be better able to sustain the forces of their new function.

After a certain amount of bone is excavated, the osteoclasts begin to die and bone resorption stops. In the third step of bone remodeling, the site is prepared for building. In this stage, sugars and proteins accumulate along the bone's surface, forming a cement line which acts to form a strong bond between the old bone and the new bone that will be made. These first three steps take approximately two to three weeks to complete. In the last step of bone remodeling, osteoblasts lay down new osteoid tissue that fills up the cavities that were excavated during the resorption process. Osteoid is bone matrix tissue that is composed of proteins such as collagen and is not mineralized yet. To make collagen, vitamin C is required. A symptom of vitamin C deficiency (known as scurvy) is bone pain, which is caused by diminished bone remodeling. After the osteoid tissue is built up, the bone tissue begins to mineralize. The last step of bone remodeling continues for months, and for a much longer time afterward the mineralized bone is continuously packed in a more dense fashion.

Thus, we can say that bone is a living tissue that continually adapts itself to mechanical stress through the process of remodeling. For bone tissue to remodel certain nutrients such as calcium, phosphorus, magnesium, fluoride, vitamin D, and vitamin K are required.

BONE MINERAL DENSITY IS AN INDICATOR OF BONE HEALTH

Bone mineral density (BMD) is a measurement of the amount of calcified tissue in grams per centimeter squared of bone tissue. BMD can be thought of as the total amount of bone mass in a defined area. When BMD is high, bone strength will be great. Similar to measuring blood pressure to predict the risk of stroke, a BMD measurement can help predict the risk of bone fracture. The most common tool used to measure BMD is called dual energy X-ray absorptiometry (DEXA). During this procedure, a person lies on their back and a DEXA scanner passes two X-ray beams through their body. The amount of X-ray energy that passes through the bone is measured for both beams. The total amount of the X-ray energy that passes through a person varies depending on their bone thickness. Using this information and a defined area of bone, the amount of calcified tissue in grams per unit area (cm²) is calculated. Most often the DEXA scan focuses on measuring BMD in the hip and the spine. These measurements are then used as indicators of overall bone strength and health. DEXA is the cheapest and most accurate way to measure BMD. It also uses the lowest dose of radiation. Other

methods of measuring BMD include quantitative computed tomography (QCT) and radiographic absorptiometry. People at risk for developing bone disease are advised to have a DEXA scan. We will discuss the many risk factors linked to an increased incidence of osteoporosis and the steps a person can take to prevent the disease from developing.



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The Immune System

The immune system comprises several types of white blood cells that circulate in the blood and lymph. Their jobs are to seek, recruit, attack, and destroy foreign invaders, such as bacteria and viruses. Other less realized components of the immune system are the skin (which acts as a barricade), mucus (which traps and entangles microorganisms), and even the bacteria in the large intestine (which prevent the colonization of bad bacteria in the gut). Immune system functions are completely dependent on dietary nutrients. In fact, malnutrition is the leading cause of immune-system deficiency worldwide. When immune system functions are inadequate there is a marked increase in the chance of getting an infection. Children in many poor, developing countries have protein- and/or energy-deficient diets that are causative of two different syndromes, kwashiorkor and marasmus. These children often die from infections that their bodies would normally have fought off, but because their protein and/or energy intake is so low, the immune system cannot perform its functions.

Other nutrients, such as iron, zinc, selenium, copper, folate, and vitamins A, B6, C, D, and E, all provide benefits to immune system function. Deficiencies in these nutrients can cause an increased risk for infection and death. Zinc deficiency results in suppression of the immune system's barrier functions by damaging skin cells; it is also associated with a decrease in the number of circulating white blood cells. A review of several studies in the journal *Pediatrics* concluded that zinc supplements administered to children under age five for longer than three months significantly reduces the incidence and severity of diarrhea and respiratory illnesses.¹

Zinc supplementation also has been found to be therapeutically beneficial for the treatment of leprosy, tuberculosis, pneumonia, and the common cold. Equally important to remember is that multiple studies show that it is best to obtain your minerals and vitamins from eating a variety of healthy foods.

Just as undernutrition compromises immune system health, so does overnutrition. People who are obese are at increased risk for developing immune system disorders such as asthma, rheumatoid arthritis, and some cancers. Both the quality and quantity of fat affect immune system function. High intakes of saturated and trans fats negatively affect the immune system, whereas increasing your intake of omega-3 fatty acids, found in salmon and other oily fish, decreases inflammatory responses. High intakes of omega-3 fatty acids are linked to a reduction in the risk of developing certain autoimmune disorders, such as rheumatoid arthritis, and are used as part of a comprehensive treatment for rheumatoid arthritis.



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Notes

1. Aggarwal R, Sentz J, Miller MA. Role of Zinc Administration in Prevention of Childhood Diarrhea and Respiratory Illnesses: A Meta-Analysis. *Pediatrics*. 2007; 119(6), 1120–30. <https://www.ncbi.nlm.nih.gov/pubmed/17545379>. Accessed September 22, 2017.

Indicators of Health: Body Mass Index, Body Fat Content, and Fat Distribution

Although the terms overweight and obese are often used interchangeably and considered as gradations of the same thing, they denote different things. The major physical factors contributing to body weight are water weight, muscle tissue mass, bone tissue mass, and fat tissue mass. Overweight refers to having more weight than normal for a particular height and may be the result of water weight, muscle weight, or fat mass. Obese refers specifically to having excess body fat. In most cases people who are overweight also have excessive body fat and therefore body weight is an indicator of obesity in much of the population.

The “ideal” healthy body weight for a particular person is dependent on many things, such as frame size, sex, muscle mass, bone density, age, and height. The perception of the “ideal” body weight is additionally dependent on cultural factors and the mainstream societal advertisement of beauty.

To standardize the “ideal” body weight and relate it to health, scientists have devised mathematical formulas to better define a healthy weight. These mathematically derived measurements are used by health professionals to correlate disease risk with populations of people and at the individual level. A clinician will take two measurements, one of weight and one of fat mass, in order to diagnose obesity. Some measurements of weight and body fat that do not require using technical equipment can easily be calculated and help provide an individual with information on weight, fat mass, and distribution, and their relative risk of some chronic diseases.

Figure 2.28 Body Composition

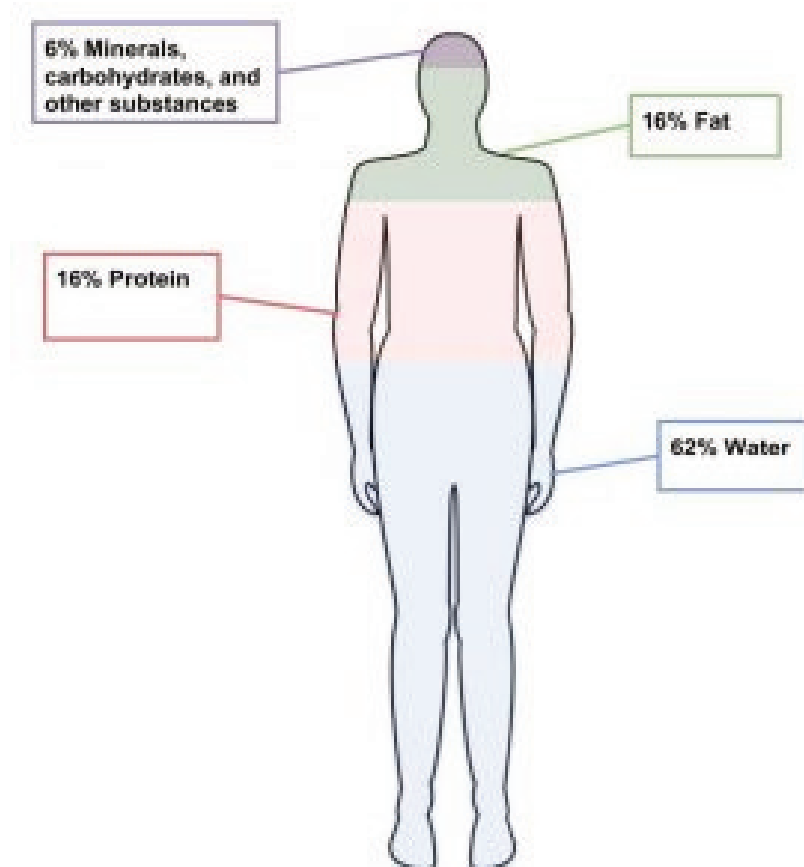


Image by Allison Calabrese / CC BY 4.0

BODY MASS INDEX: HOW TO MEASURE IT AND ITS LIMITATIONS

Body mass index (BMI) is calculated using height and weight measurements and is more predictive of body fatness than weight alone. BMI measurements are used to indicate whether an individual may be underweight (with a BMI less than 18.5), overweight (with a BMI over 25), or obese (with a BMI over 30). High BMI measurements can be warning signs of health hazards ahead, such as cardiovascular disease, Type 2 diabetes, and other chronic diseases. BMI-associated health risks vary by race. Asians face greater health risks for the same BMI than Caucasians, and Caucasians face greater health risks for the same BMI than African Americans.

Calculating BMI

To calculate your BMI, multiply your weight in pounds by 703 (conversion factor for converting to metric units) and then divide the product by your height in inches, squared.

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

or

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

More Ways to Calculate

The National Heart, Lung, and Blood Institute and the CDC have automatic BMI calculators on their websites:

- <https://www.nhlbisupport.com/bmi/>
- https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/english_bmi_calculator/bmi_calculator.html

To see how your BMI indicates the weight category you are in, see Table 2.3 “BMI Categories” or use a chart of weight and height to figure out your BMI.

Table 2.3 BMI Categories

Categories	BMI
Underweight	< 18.5
Normal weight	18.5–24.9
Overweight	25–29.9
Obese	> 30.0

Source: National Heart, Lung, and Blood Institute. Accessed November 4, 2012. <https://www.nhlbi.nih.gov>.

BMI Limitations

A BMI is a fairly simple measurement and does not take into account fat mass or fat distribution in the body, both of which are additional predictors of disease risk. Body fat weighs less than muscle mass. Therefore, BMI can sometimes underestimate the amount of body fat in overweight or obese people and overestimate it in more muscular people. For instance, a muscular athlete will have more muscle mass (which is heavier than fat mass) than a sedentary individual of the same height. Based on their BMIs the muscular athlete would be less “ideal” and may be categorized as more overweight or obese than the sedentary individual; however this is an infrequent problem with BMI calculation. 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 more fat mass. BMI is a useful inexpensive tool to categorize people and is highly correlative with disease risk, but other measurements are needed to diagnose obesity and more accurately assess disease risk.

Body Fat and Its Distribution

Next we’ll discuss how to measure body fat, and why distribution of body fat is also important to consider when determining health.

Measuring Body Fat Content

Water, organs, bone tissue, fat, and muscle tissue make up a person’s weight. Having more fat mass may be indicative of disease risk, but fat mass also varies with sex, age, and physical activity level. Females have more fat mass, which is needed for reproduction and, in part, is a consequence of different levels of hormones. The optimal fat content of a female is between 20 and 30 percent of her total weight and for a male is between 12 and 20 percent. Fat mass can be measured in a variety of ways. The simplest and lowest-cost way is the skin-fold test. A health professional uses a caliper to measure the thickness of skin on the back, arm, and other parts of the body and compares it to standards to assess body fatness. It

is a noninvasive and fairly accurate method of measuring fat mass, but similar to BMI, is compared to standards of mostly young to middle-aged adults.

Figure 2.29 Measuring Skinfold Thickness Using Calipers



Image by Shutterstock. All Rights Reserved.

Other methods of measuring fat mass are more expensive and more technically challenging. They include:

- Underwater weighing. This technique requires a chamber full of water big enough for the whole body to fit in. First, a person is weighed outside the chamber and then weighed again while immersed in water. Bone and muscle weigh more than water, but fat does not—therefore a person with a higher muscle and bone mass will weigh more when in water than a person with less bone and muscle mass.
- Bioelectric Impedance Analysis (BIA). This device is based on the fact that fat slows down the passage of electricity through the body. When a small amount of electricity is passed through the body, the rate at which it travels is used to determine body composition. These devices are also sold for home use and commonly called body composition scales.

Figure 2.30 BIA Hand Device



Image by United States Marine Corps / Public Domain

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

Figure 2.31 Dual-Energy X-ray Absorptiometry (DEXA)



“A Dual-energy X-ray absorptiometry (DEXA) scan” by Nick Smith / CC BY-SA 3.0

Measuring Fat Distribution

Total body-fat mass is one predictor of health; another is how the fat is distributed in the body. You may have heard that fat on the hips is better than fat in the belly—this is true. Fat can be found in different areas in the body and it does not all act the same, meaning it differs physiologically based on location. Fat deposited in the abdominal cavity is called visceral fat and it is a better predictor of disease risk than total fat mass. Visceral fat releases hormones and inflammatory factors that contribute to disease risk. The only tool required for measuring visceral fat is a measuring tape. The measurement (of waist circumference) is taken just above the belly button. Men with a waist circumference greater than 40 inches and women with a waist circumference greater than 35 inches are predicted to face greater health risks.

Figure 2.32 Fat Distribution

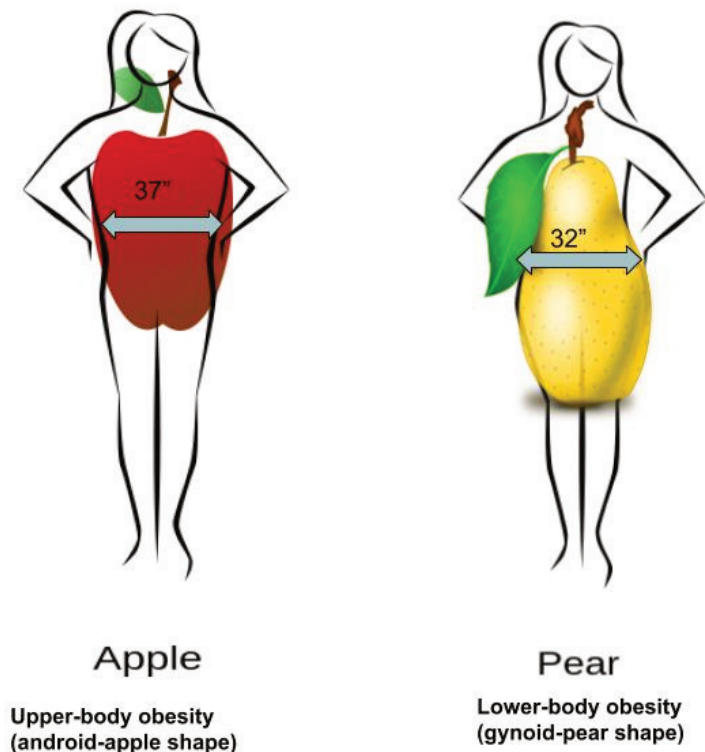


Image by Allison Calabrese / CC BY 4.0

The waist-to-hip ratio is often considered a better measurement than waist circumference alone in predicting disease risk. To calculate your waist-to-hip ratio, use a measuring tape to measure your waist circumference and then measure your hip circumference at its widest part. Next, divide the waist circumference by the hip circumference to arrive at the waist-to-hip ratio. Observational studies have demonstrated that people with “apple-shaped” bodies, (who carry more weight around the waist) have greater risks for chronic disease than those with “pear-shaped” bodies, (who carry more weight around the hips). A study published in the November 2005 issue of *Lancet* with more than twenty-seven thousand participants from fifty-two countries concluded that the waist-to-hip ratio is highly correlated with heart attack risk worldwide and is a better predictor of heart attacks than BMI.¹ Abdominal obesity is defined by the World Health Organization (WHO) as having a waist-to-hip ratio above 0.90 for males and above 0.85 for females.



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Notes

1. Yusuf S, Hawken S, et al. Obesity and the Risk of Myocardial Infarction in 27,000 Participants from 52 Countries: A Case-Control

Study. *Lancet*. 2005; 366(9497), 1640–9. <http://www.ncbi.nlm.nih.gov/pubmed/16271645?dopt=AbstractPlus>. Accessed September 22, 2017.

