wonders of the HUMAN BODY

Volume 1

The Musculoskeletal System | The Cardiovascular & Respiratory Systems | The Nervous System

MASTERBOOKS® CURRICULUM

Dr. Tommy Mitchell

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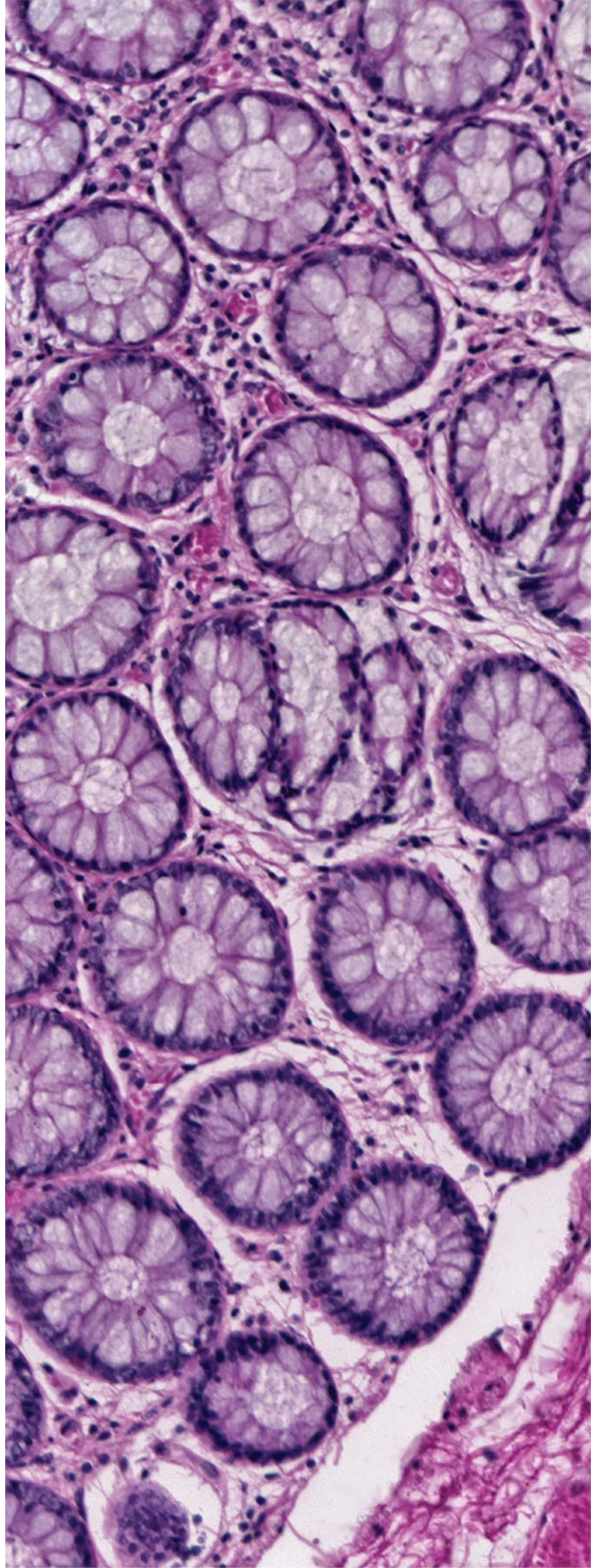
Dedication

For my beloved wife, Elizabeth



Cross section of glandular ducts

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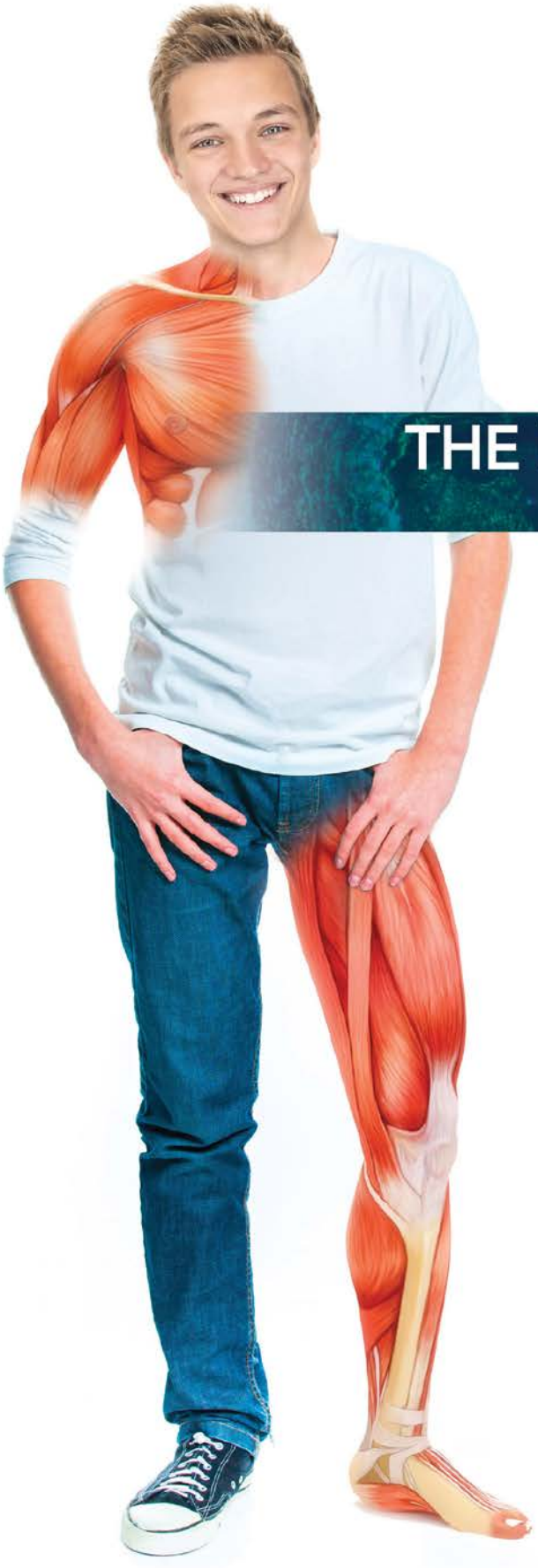


UNIT 1

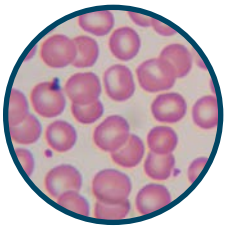
THE MUSCULOSKELETAL SYSTEM

wonders of the HUMAN BODY

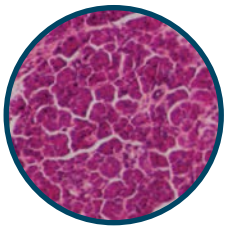
2

CELLS

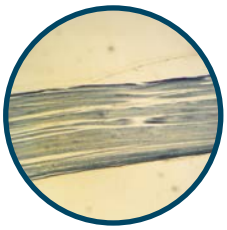
The cell is not only the basic building block of the body but also the basic "functional unit." What does that mean? Well, your body does a lot of things — some things you see and some that you don't. It moves. It grows. It digests food, turning some of it into energy, storing some of it, and discarding the leftovers. It manufactures many kinds of complex chemicals. It tastes, smells, sees, hears, touches, senses temperature, and feels pain. It takes in oxygen from the air and carries it all over your body. It fights infection and protects you from most germs. It stops you from bleeding when you get a cut, and later it heals the cut. All these "functions" are really performed by or inside cells. That's why we say the cell is the smallest "functional unit" of the body. The cell is where the action is!



Blood Cell

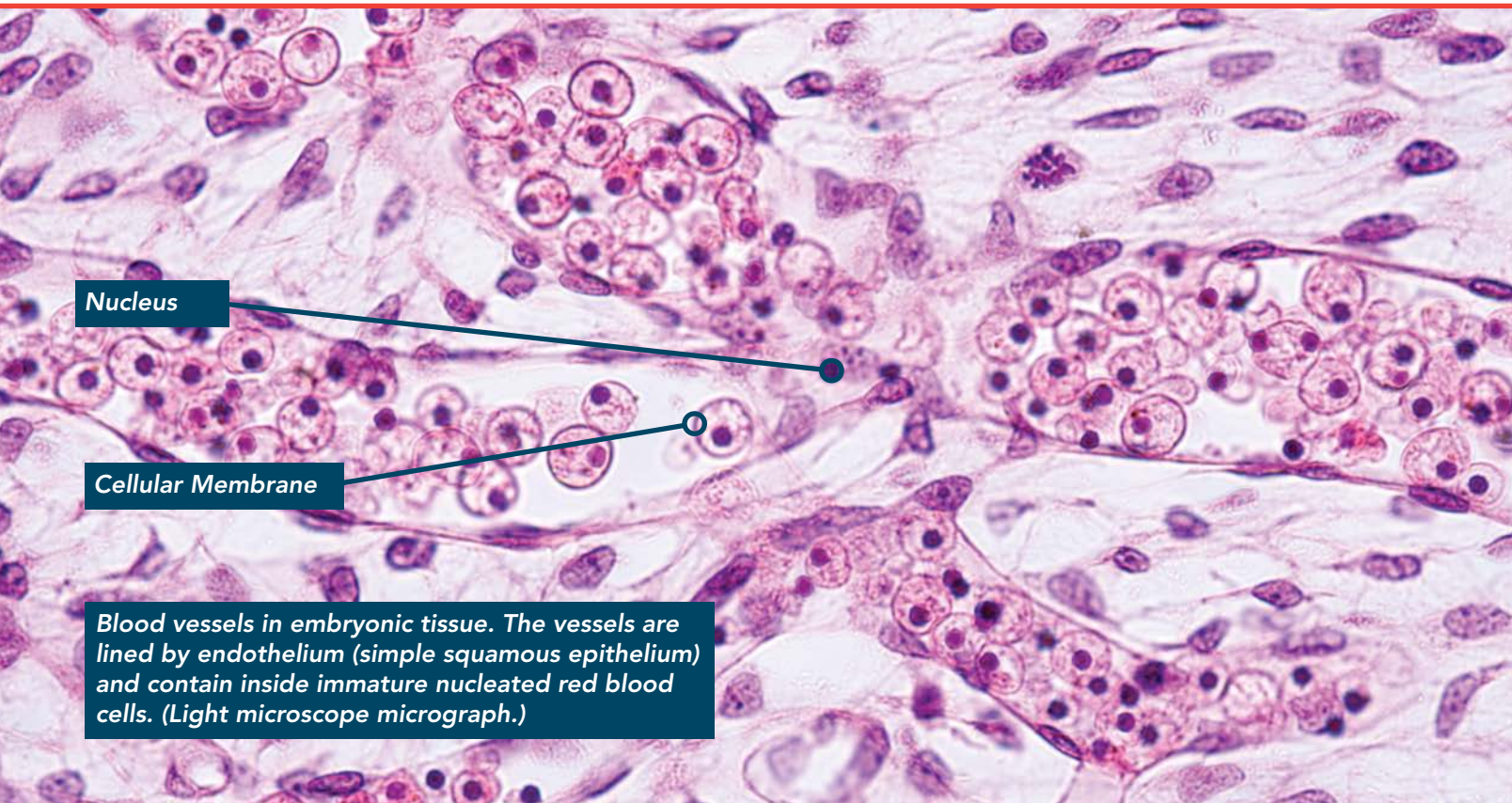


Liver Cell



Muscle Cell

Nerve Cell



Blood vessels in embryonic tissue. The vessels are lined by endothelium (simple squamous epithelium) and contain inside immature nucleated red blood cells. (Light microscope micrograph.)

Each cell is like a factory designed to carry out a specific function. There are over 200 different kinds of cells in the human body, and they come in all shapes and sizes. Most cells have three basic parts — a *nucleus* that directs most of the action, a *cell membrane* that forms the cell's outer border, and *cytoplasm* where most of the cell's work gets done. Most kinds of cells have many *organelles* that perform the various jobs in the cell.

Erythrocytes are red blood cells. Their main job is to carry oxygen. Red blood cells are packed with a red oxygen-carrying molecule (hemoglobin), which is why they are red. Erythrocytes are comparatively simple cells. The erythrocytes circulating throughout your body don't even have a nucleus or organelles.

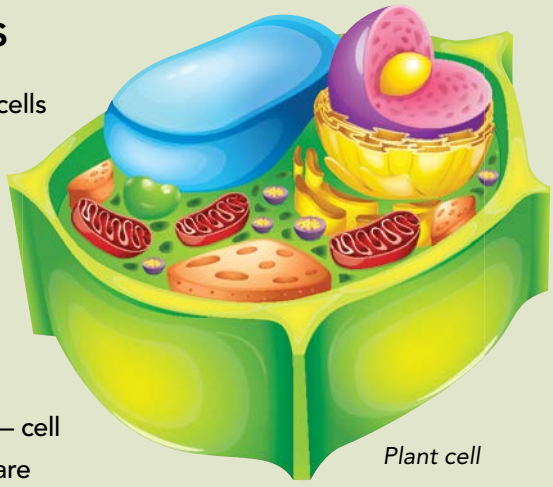
In contrast, liver cells are much more complex. Liver cells process and store nutrients, manufacture important substances, and rid the body of some toxic chemicals. Because liver cells are involved in more complex activities than red blood cells, their structure is more complex.

Each muscle cell is designed to contract, and you can move because muscle cells work together. Certain cells in the pancreas produce *insulin* that controls the amount of sugar in your blood, because either too much or too little is bad for you. Nerve cells transmit nerve impulses so that one part of your body can communicate with another. Otherwise, your hand would not "know" that your brain told it to move. And the list goes on. Each cell has an important job to do.

For all their many differences in structure and function, most cells have a lot of things in common. Here we'll learn about a "typical" cell. Then in our journey through the human body, we will examine specific cell types in more detail.

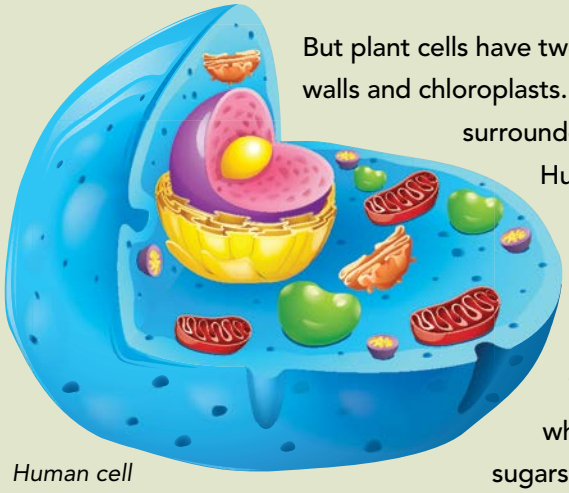
Human Cells and Plant Cells

You will soon learn about many different kinds of cells found in the human body. Plants are also made of cells. Plant cells have many things in common with our cells. Plant cells have nuclei containing chromosomes that direct the cellular activities. They have mitochondria and the other organelles we have. And plant cells also have cell membranes.



Plant cell

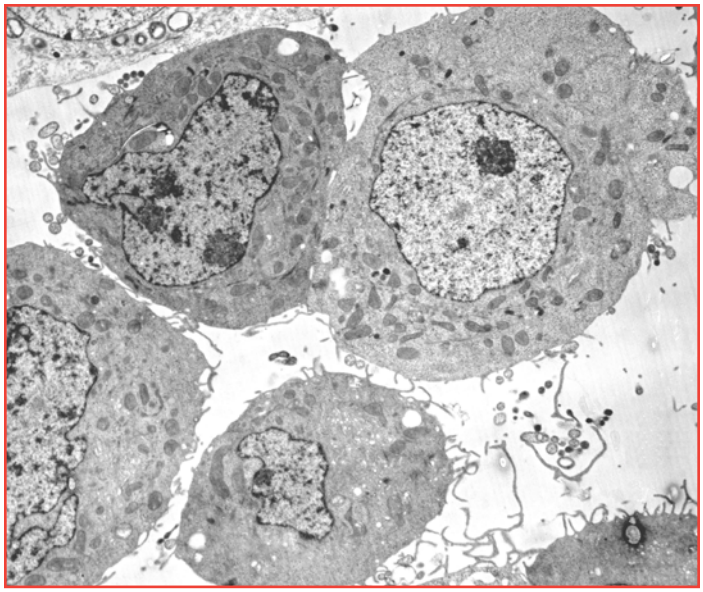
But plant cells have two things our cells lack — cell walls and chloroplasts. Plant cell membranes are surrounded by a tough cell wall made of cellulose. Humans cannot make cellulose. The cell wall provides a sturdy support for plant cells and helps maintain their shape. Plant cells, unlike our cells, are also able to capture energy directly from sunlight and use it to manufacture sugar. This process is called photosynthesis. Photosynthesis takes place in special organelles called chloroplasts. The chloroplasts in plant cells contain the green pigment chlorophyll, which captures the sun's energy. God designed plant cells to produce sugars and other important foods for humans and animals to eat.



Human cell

Basic Cell Structure

Regardless of size, shape, or complexity, most human cells have, as we mentioned, three main parts. The *cell membrane*, also called the *plasma membrane*, encloses the cell, forming the boundary with its *extracellular* surroundings. One could look at the plasma membrane as the bag or sack that holds all the other parts. This is no ordinary "bag" though. Even the membrane surrounding the cell is specially designed to perform a lot of vital jobs. The cell membrane keeps some things in and keeps other things out, while letting some things travel across it and actively helping other things to pass through. The cell membrane is like the ultimate doorkeeper, and then some!



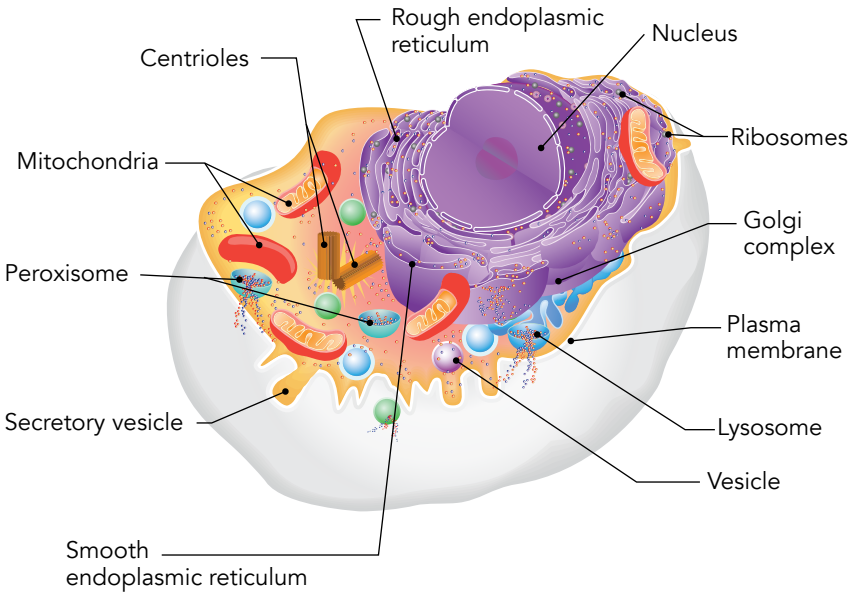
Electron microscopic view of cells

The control center of the cell is the *nucleus*. It directs the activities of the cell. The nucleus stores all the instructions the cell needs to function. These instructions are in code. The code is written into the structure of DNA, long chain-like molecules that are stored in the nucleus.
The blueprint for making each protein the cell it is supposed to make is written in a *gene* in this DNA. Except for mature red blood cells, all cells in the body have at least one nucleus. Some have several *nuclei*.

In between the cell membrane and the nucleus, or nuclei, is the *cytoplasm*. All the parts of the cell that are not part of the nucleus or cell membrane are part of the cytoplasm. Many little "workstations" called *organelles* float in the *cytosol*, which is the cytoplasm's fluid. Dissolved in the cytosol are also many substances like sugars and electrolytes. (*Electrolytes* include sodium ions, potassium ions, calcium ions, and so forth. *Ions* are charged chemicals, and we'll learn later that the way they move into and out of cells is very important.) Large molecules such as enzymes also float around in the cytosol, each doing an important job.

TAKING A CLOSER LOOK

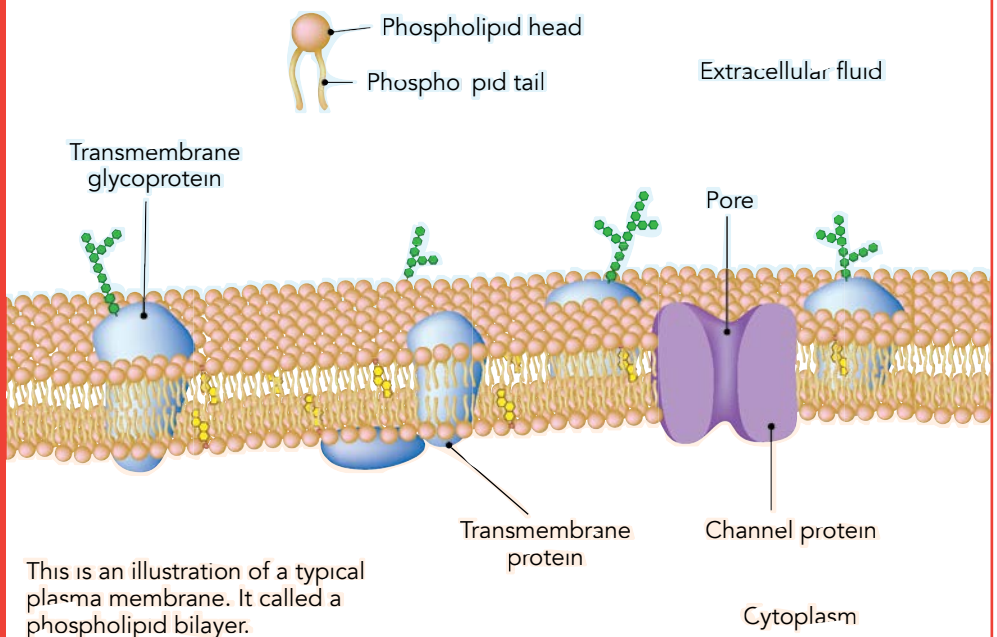
Human Cell Structure



The Plasma Membrane

TAKING A CLOSER LOOK

Plasma Membrane Structure



This is an illustration of a typical plasma membrane. It called a phospholipid bilayer.

The plasma membrane is the envelope that contains the other components of the cell. Within it is the cytoplasm, its organelles, and the nucleus. Without the plasma membrane, the cell would have no form or structure. The plasma membrane holds the cell together.

However, the plasma membrane is far more than just a container. It helps separate the two major fluid compartments of the body, the *intracellular fluid* — fluid inside cells — from the *extracellular fluid* — fluid that is outside cells. The plasma membrane is also involved in moving fluid, nutrients, and other substances into and out of the cell while forming a barrier to things that should stay out.

Most of the intracellular fluid and most of the extracellular fluid is water, but the concentration of the chemicals dissolved in them makes them very, very different. The chemicals dissolved in these fluids are "water soluble," which means they can dissolve in water. You probably already know that sugar and salt dissolve in water, and oil does not. Well, sugar molecules are water-soluble. Salts are made of ions, like sodium ions and potassium ions and chloride ions, and such salts are also water-soluble. Fats and oils, however, are not water-soluble: they do not dissolve in water. Another name for a fat is *lipid*.

Its Structure

The plasma membrane is actually made up of two layers of molecules. These molecules are called *phospholipids*, and they have a very interesting shape, as you can see in the illustration.

These molecules have what can be described as a "head" and two "tails." The "head" of the molecule is charged. This portion of the molecule is water-soluble (known as *hydrophilic*, a word that literally means "water-loving") and is therefore attracted to water. The tail portion is uncharged and avoids water (known as *hydrophobic*, a word that literally means "water-fearing"). These characteristics of phospholipids are important not only in the structure of the plasma membrane, but also for its function.

The plasma membrane is composed of these two layers of phospholipids, creatively called a *phospholipid bilayer*, which means "two layers of phospholipids." The phospholipid molecules are lying with the heads facing the outer and inner surface of the plasma membrane and the tails pointing to the interior of the membrane. The hydrophilic (water-loving) heads of the molecules are in contact with the watery fluid inside and outside the cells. The hydrophobic

(water "fearing") tails are pointing toward each other, as far from the watery fluids as possible. This helps maintain the integrity of the membrane.

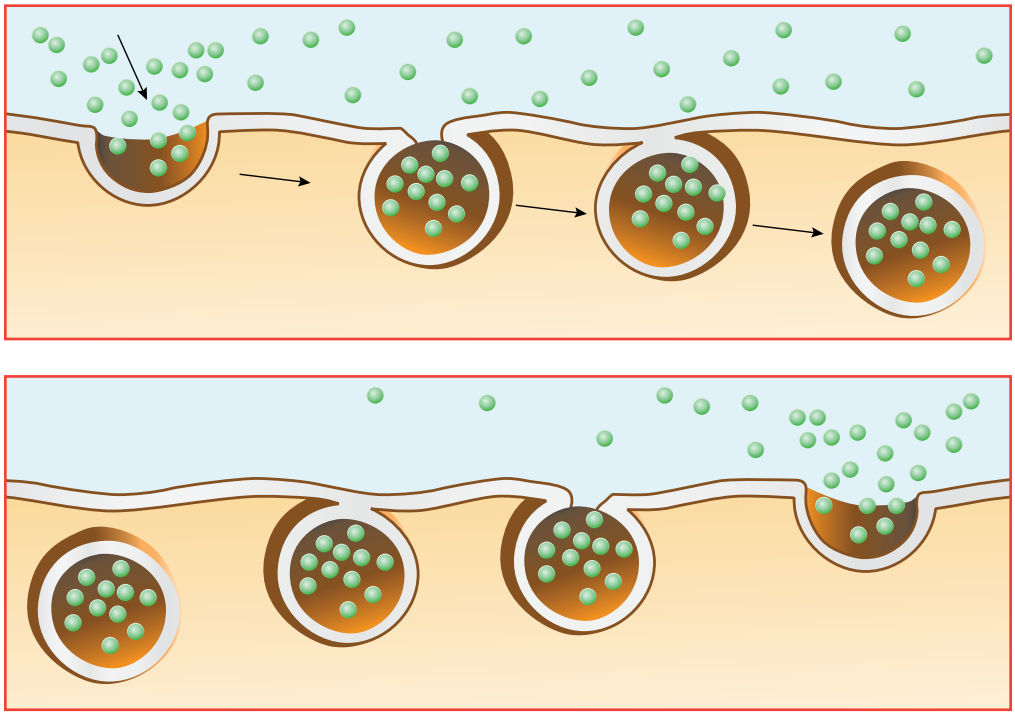
In addition to the phospholipids, the plasma membrane has a lot of protein molecules embedded in it. Some of these proteins extend completely through the plasma membrane. Some are only attached to its inner or outer surface. These proteins are vital to the normal function of the cell. Some of them ferry certain substances across the membrane. Some form a doorway allowing particular sorts of molecules to pass through. Some of them are like name tags that identify the cell to other cells. Some even form attachments to other neighboring cells.

Its Function

So beyond just holding the contents of the cell in one container, what is the function of the plasma membrane? Well, among other things, it helps regulate what goes into and out of the cell.

Some substances, like water and certain lipid (fat) molecules, can pass directly through the plasma membrane and get into or out of the cell. However, many other substances cannot easily get into cells. Often, these can gain access to the cell by means of some of the proteins in the plasma membrane. These special proteins have a channel in them to allow things into a cell that could not pass directly through the plasma membrane.

Some things, however, are too large even for protein channels. So in the case of the largest molecules, there is a special mechanism called *endocytosis*. In this case, a portion of the plasma membrane folds into the cell, surrounds the molecules needed, and then the membrane pinches off, forming a small bubble-like *vesicle*, which is then processed inside the cell. Occasionally this process is reversed and vesicles formed within the cell merge with the plasma membrane and release products made by the cell. The process of releasing material from inside the cell is called *exocytosis*.



Vesicles can transport material into and out of cells. During endocytosis, shown on top, material is transported into a cell by packaging it into a vesicle. Exocytosis is shown in the bottom illustration. There, a vesicle merges with the cell membrane and the material it contains is released.

Further, the plasma membrane is able to respond to cellular signals because of some of the proteins on its outer surface. These proteins bind to certain molecules that cause the cell to react in a specific way.

There are also special proteins on the outer surface of the plasma membrane that help identify the cell. In other words, these proteins are like an identification tag for the cell, so the body itself can know which cells are which. When we study the immune system, you will see this in action. So the plasma membrane isn't just any old bag, is it?

Cell Markers

The plasma membrane contains some special proteins called glycoproteins. These proteins have carbohydrate (sugar) groups attached that protrude into the extracellular fluid. These carbohydrate groups along with other special molecules called glycolipids form a coating on the cell surface known as the glycocalyx.

The pattern of the glycocalyx varies from cell to cell. It is distinctive enough that it forms a molecular "signature" for a cell. This is one way that cells can recognize one another.

Cytosol

Cytosol is the liquid found inside the cell. It surrounds the organelles and the nucleus. The *cytosol* plus the *organelles* make up the *cytoplasm*.

The cytosol is mostly water. Water makes up 70 to 75 percent of the volume of the cell. The cytosol contains many substances, and the cell works hard to maintain the appropriate balance of the substances found there.

There are lots of ions (charged atoms or molecules) in the cytosol, mostly potassium, sodium, chloride, and bicarbonate ions. These ions help maintain the electrical balance between the inside and outside of the cell (called the *membrane potential*, as we will explore later), as well as help maintain the correct water concentration inside the cell.

The cytosol also contains lots of proteins and *amino acids*. (Amino acids are the building blocks of proteins; we'll get more into that later.) These proteins and amino acids provide the raw materials for many of the activities of the cell.

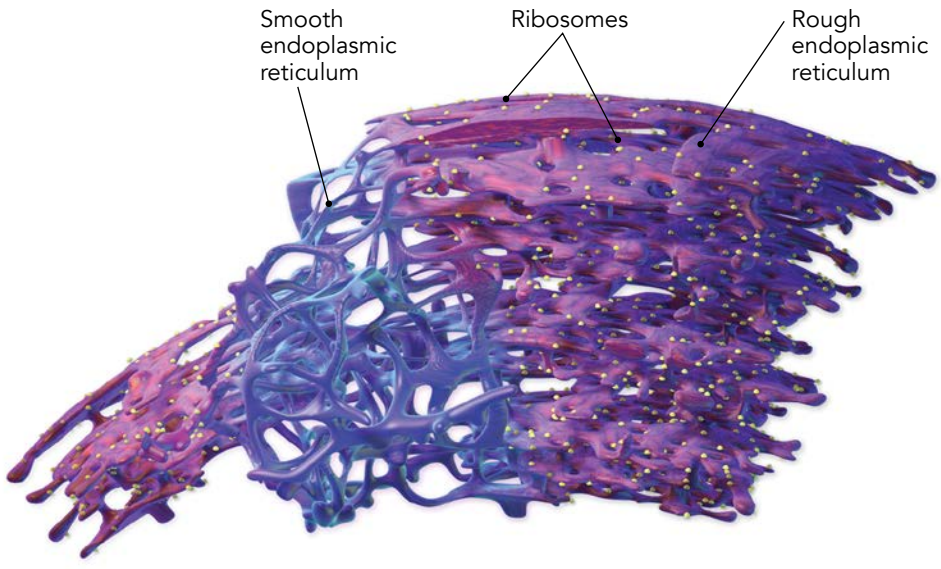
Endoplasmic Reticulum

The *endoplasmic reticulum* is a network of tubes and membranes that is connected to the nuclear membrane. The endoplasmic reticulum, or ER, comes in two forms, *rough ER* and *smooth ER*.

Rough ER is bumpy because it is covered with *ribosomes*. Ribosomes are little factories for making protein. Rough ER is primarily involved with protein production. Proteins that are made in the ribosomes can be modified by the endoplasmic reticulum to fit them for their particular jobs. The particular proteins and lipids that make up the plasma membrane are made in the rough ER.

TAKING A CLOSER LOOK

Endoplasmic Reticulum



Smooth ER is more tube-like in appearance and is not covered with ribosomes. It is more involved with production of fats, certain hormones, and the break-down of some toxins that enter the cell.

Golgi Apparatus

The Golgi apparatus is a collection of small flattened sacs that stack on one another. They tend to be flatter in the middle and more rounded on the ends.

Cells produce lots of things, especially fats and proteins. The Golgi apparatus helps the cell transport these products to where they are needed. It does this by forming little sacs, or vesicles, around the needed items. These vesicles pinch off from the Golgi apparatus and travel to their destination. Sometimes this is within the cell itself. Sometimes the vesicle moves to the plasma membrane and releases its contents outside the cell via *exocytosis*.

The Golgi apparatus is an exquisitely designed delivery system. Without it, the cell could not function.

Lysosomes

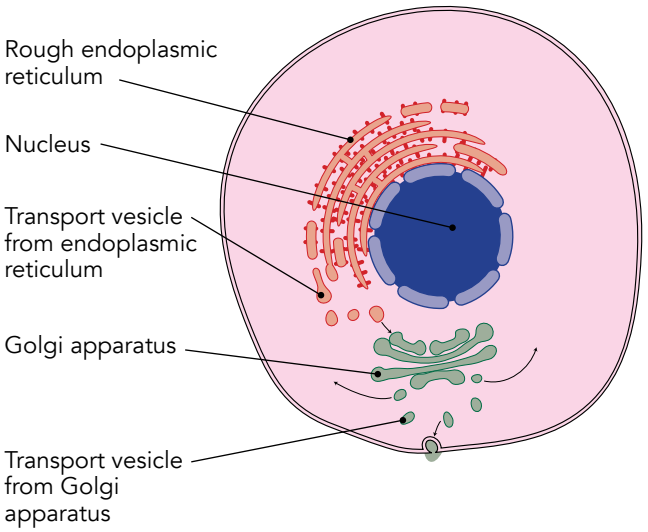
Lysosomes are small vesicles containing enzymes that can digest many kinds of molecules and debris. This may seem surprising. After all, aren't these types of substances dangerous to the cell itself? Yes, they can be, but they are still very necessary.

Lysosomes break down worn-out organelles, bacteria, and toxic substances. For example, white blood cells contain a large number of lysosomes. That is how they are able to help rid the body of invading bacteria.

Lysosomes also aid the cell by breaking down substances the cell needs for nutrition, particularly large molecules the cell takes in. In fact, the lysosome is sometimes called the "stomach" of the cell. And by breaking down organelles that are worn out or no longer needed, the lysosomes recycle valuable materials.

TAKING A CLOSER LOOK

The Golgi at Work



Here we see vesicles carrying material from the rough ER to the Golgi apparatus. In the Golgi these materials are modified and packaged into new vesicles. Some of these vesicles then release material to the outside.

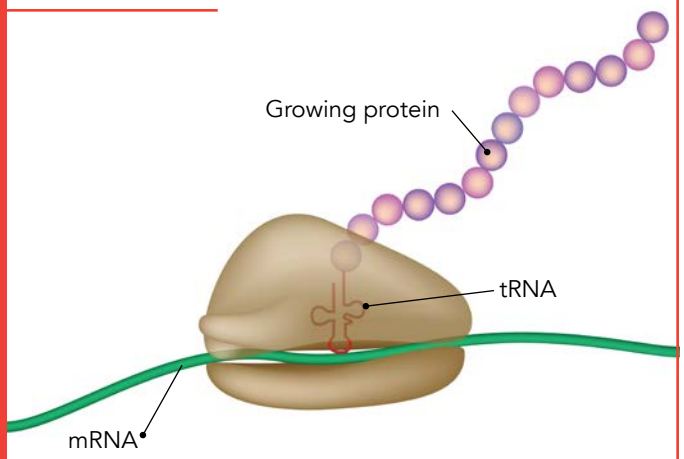
Ribosomes

Ribosomes are found floating in the cytoplasm and attached to the rough endoplasmic reticulum. These are little structures, but they have a very big job. *Ribosomes* are where proteins are made. Let's consider where a ribosome gets its protein-building instructions.

You may remember that the nucleus of a cell directs the cell's activities. The instructions for what the cell is supposed to do are stored in the nucleus. The "blueprints" for how to build the proteins a cell is supposed to build are mostly stored in the nucleus. These "blueprints" or "recipes" for building proteins are called genes.

TAKING A CLOSER LOOK

Ribosomes



Genes with protein-building instructions are in the nucleus, but the protein-making ribosomes are located in the cytoplasm. How can the ribosomes get their instructions? Well, copies of the instructions, called *messenger RNA*, are made in the nucleus. Those messages move from the nucleus into the cytoplasm. There, ribosomes read the messenger RNA's instructions and build the protein described, stitching together a string of *amino acids*, which are the building blocks of proteins. The ribosome follows the "recipe" stored in the nucleus and copied onto messenger RNA.

Mitochondria

The *mitochondria* are often called the "powerhouses" of the cell. They are called that because they generate and store energy. Mitochondria are like super battery chargers.

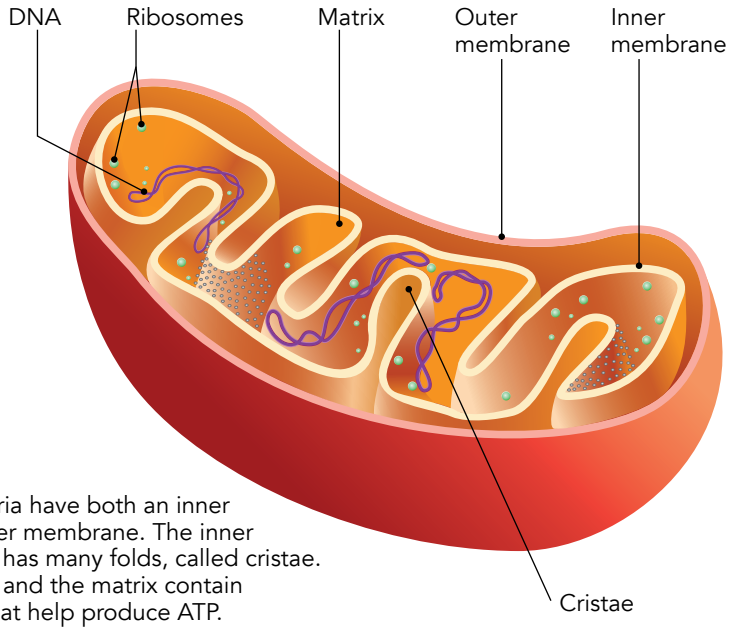
These are elongated bean-shaped structures with lots of folded membranes inside. Unlike the other organelles in the cell, mitochondria even contain some genes used to reproduce themselves! (Remember, all the rest of the genes in your body's cells are stored in the nuceli.)

The mitochondria are responsible for producing high-energy molecules. Those high-energy molecules are like batteries: they store energy until the cell needs the energy for something. One of the most important high-energy molecules is ATP (which stands for *adenosine triphosphate*, if you want to show off to your friends . . .). This molecule stores energy needed to fuel cellular activities.

ATP is actually built from ADP, *adenosine diphosphate*. ADP is like a battery that needs to be recharged. And ATP is like a fully charged battery. As you might guess from the names *triphosphate* and *biphosphate*, ATP contains three "phosphates" and ADP contains two "phosphates." The bonds that hold phosphate onto ADP and ATP store a lot of energy,

TAKING A CLOSER LOOK

Mitochondria



Mitochondria have both an inner and an outer membrane. The inner membrane has many folds, called cristae. The cristae and the matrix contain enzymes that help produce ATP.

Making Mitochondria

The nucleus is not the only place that DNA is found in the cell. Mitochondria have multiple copies of their own DNA. This DNA exists as a circular molecule containing 37 genes. Interestingly enough, mitochondrial DNA is inherited only from the mother. In addition, mitochondria contain RNA and ribosomes. During times of increased energy needs, the mitochondria can reproduce themselves to increase their number. They grow and divide by pinching in half.

much like a battery stores energy until it is needed. When energy is needed, a high-energy bond in ATP (or in other similar high-energy molecules) is broken and the energy released from it is used to power whatever the cell needs to do.

But where does the mitochondria get the energy to charge these chemical batteries? After all, you've learned before that energy cannot be created or destroyed but only transformed from one form to another. The fuel that provides the energy for the mitochondria's charging operation comes from sugar.

The process of providing energy to the cell is kind of like putting wood in a stove or putting gasoline in a car. Wood and gasoline are both fuels. The wood in the stove burns to make heat that can be used to cook food or heat your home. The gasoline in a car is burned by the engine and provides energy to make the car move. It is not all that different to make energy for a cell. The cell's favorite fuel is not wood or gasoline but the sugar *glucose*. The energy produced when it is *metabolized* — a sort of very controlled way of "burning" the fuel — must be captured and stored in chemical "batteries" like ATP.

Remember, think of ATP and ADP like rechargeable batteries. The primary fuel for cells is the sugar glucose. Glucose is taken into the mitochondria through a series of chemical reactions, and the molecule ATP is produced by recharging ADP with energy from glucose. Just as burning wood or gasoline depends on oxygen, this chain of chemical reactions in the mitochondria also requires oxygen (so thank your lungs here!).

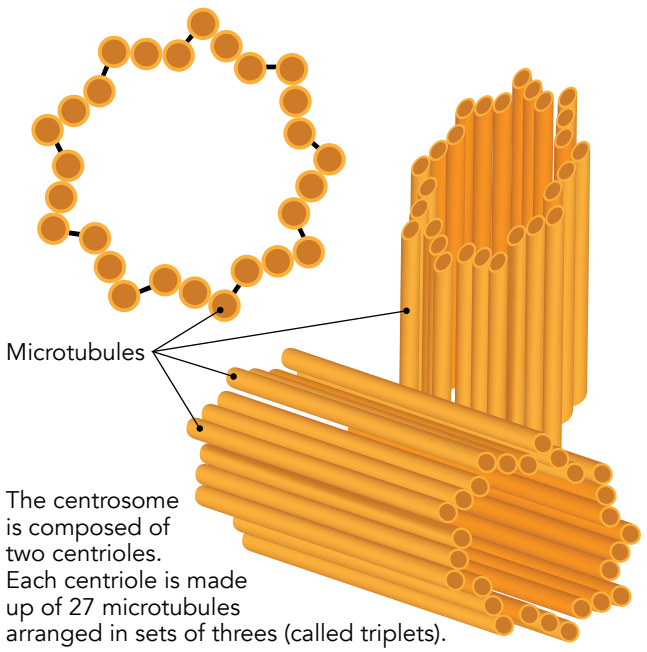
The number of mitochondria in a cell depends on the energy needs of the cell. Liver cells, for example, are involved in making proteins, making cholesterol and other lipids (fats), making and secreting bile, and many other things. So you may well imagine that it takes lots of energy to perform all these functions. In fact, a liver cell can have as many as 2,000 mitochondria!

Centrosome and Cytoskeleton

You might ask yourself, "What keeps all this stuff in place?" Well, there is an answer! The cell has a sort

TAKING A CLOSER LOOK

Centrosome



The centrosome is composed of two centrioles. Each centriole is made up of 27 microtubules arranged in sets of threes (called triplets).

of skeleton, called a cytoskeleton, that helps with that task. This cytoskeleton is composed of a network of tubes and filaments that run throughout the cell. Though not pictured in most diagrams of cells, these fine tubes and filaments provide support for the organelles.

But this support system does more than just hold things in one place. Along with the cytoskeleton, there are special motor proteins that help organelles move around. Mitochondria, lysosomes, and vesicles all move around the cell with the help of these amazing structures.

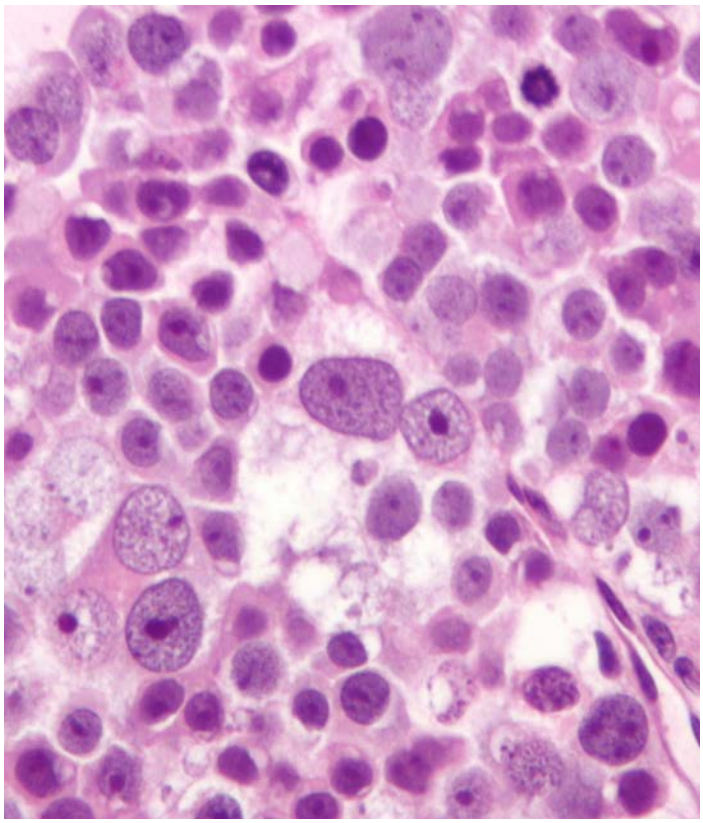
Another very special organelle, called the *centrosome*, is necessary for cellular reproduction. After all, most kinds of cells wear out and must therefore reproduce, or duplicate, themselves. We'll go into the complex process of how a cell divides in two later.

Sometimes it seems like all the action is in the nucleus when we talk about cell division. But if it weren't for the centrosome, which is located outside the nucleus in the cytoplasm, cellular reproduction would be a disorganized chaotic mess. Nothing would end up in the right place!

The centrosome is an L-shaped structure made up of two barrel-shaped *centrioles*. These centrioles are responsible for helping form a complex of *microtubules*, called the *mitotic spindle*, which guides the cell's chromosomes during cell division.

Nucleus

The nucleus is the control center of the cell. Stored in the DNA (deoxyribonucleic acid) in each cell's nucleus are the genetic instructions needed to make all the proteins in the body. The genes — the little recipes for building proteins — and even the regulations that determine how and when those genes are to be used are part of the DNA. The nucleus regulates the types of proteins made by its cell and their



Micrograph of a spermatocytic seminoma

amounts. Even though the nucleus contains a copy of your entire *genome*, only the information needed by each cell type is ever turned on and used.

The majority of cells have one nucleus. However, there are exceptions. Skeletal muscle cells (and a few other cell types) have more than one nucleus, and mature human red blood cells have none.

Just as the cell has a cell membrane, so the nucleus has a *nuclear membrane*. You recall that messages — in the form of messenger RNA — must pass from the nucleus into the cytoplasm to deliver instructions to the ribosomes. Did you wonder how the message gets through? Well, the outer part of the nuclear membrane connects to rough endoplasmic reticulum. Through tiny pores in the nuclear membrane, substances can pass from the nucleus into the cytoplasm. That way the instructions from the nucleus can reach the cytoplasm where they can be implemented.

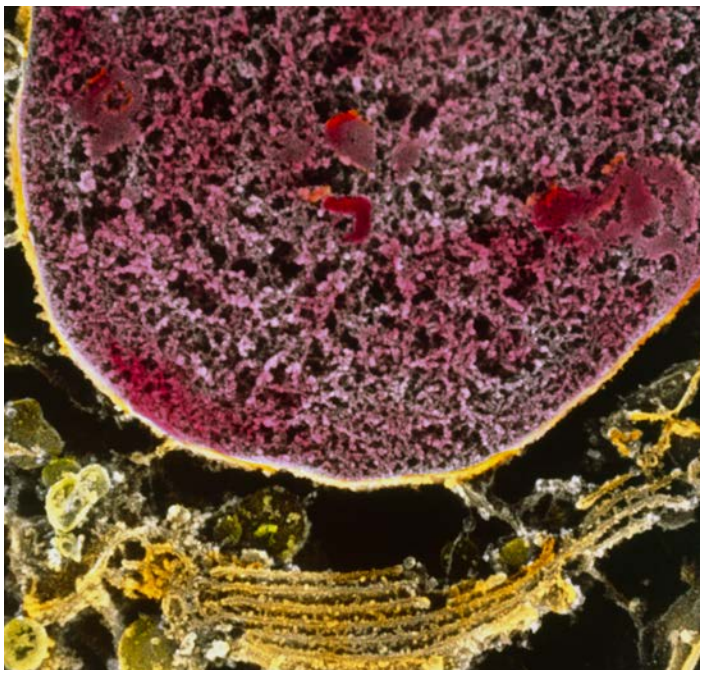
DNA

DNA — deoxyribonucleic acid — is one of the most amazing molecules in the universe. In your DNA is contained all the information needed to make your body!

DNA is a big molecule made up of two long strings of smaller molecules called *nucleotides*. There are four different kinds of nucleotides present in DNA. These four nucleotides are the building blocks of DNA. Two long strands of nucleotides are attracted to each other and form a structure that looks like a twisted ladder. That structure is called a *double helix*.

So what is so amazing about long strings of chemicals?

Well, it turns out that the order in which the nucleotides are found in DNA is very, very important. Those four nucleotides in DNA aren't just DNA's building blocks. They are the "letters" in a code — the genetic code of life that is used not only in the human body but in all the living things God designed!



Colored high resolution scanning electron micrograph of the nucleus and rough endoplasmic reticulum of a primordial testis germ cell.

You see, DNA is not just a string of chemicals. It is a very complex system of information! For decades now, scientists have studied the "letters" and "words" in the DNA and how they work.

Imagine each nucleotide as a "letter." Three "letters" form a "word." And a group of "words" can give coded instructions for building a protein or even for regulating how those instructions are carried out. The DNA in a human cell contains over 3 billion nucleotides. The instructions coded in your DNA determine which proteins can be made.

Each section of DNA that has the information for a particular protein is called a "gene." Another way of looking at this is to think of a certain group of nucleotide "words" combining to make up a genetic "book." Other sets of nucleotide words make up other books, and so on.

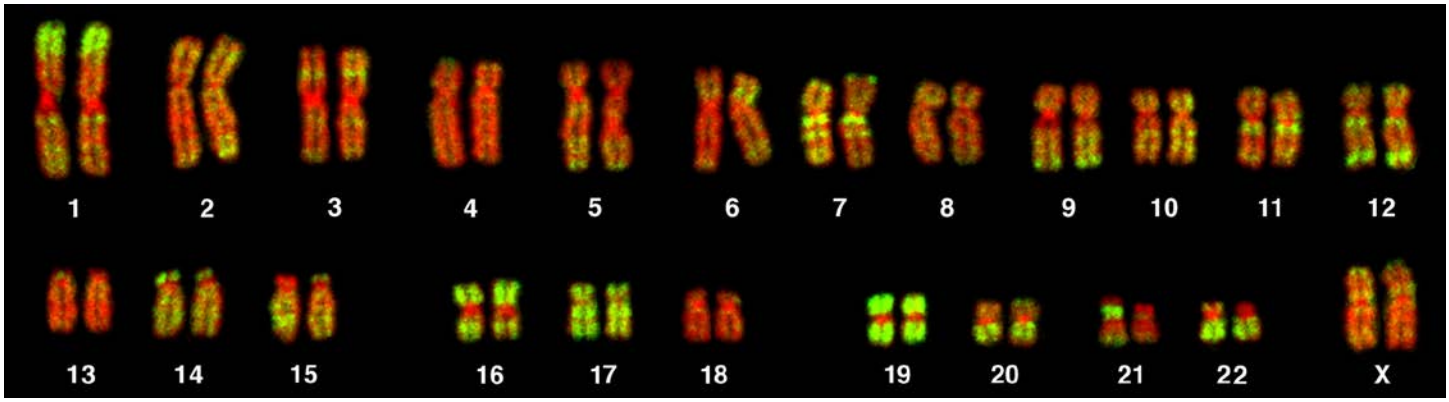
TAKING A CLOSER LOOK

DNA

DNA is made of four different nucleotides

- Adenine
- Thymine
- Cytosine
- Guanine

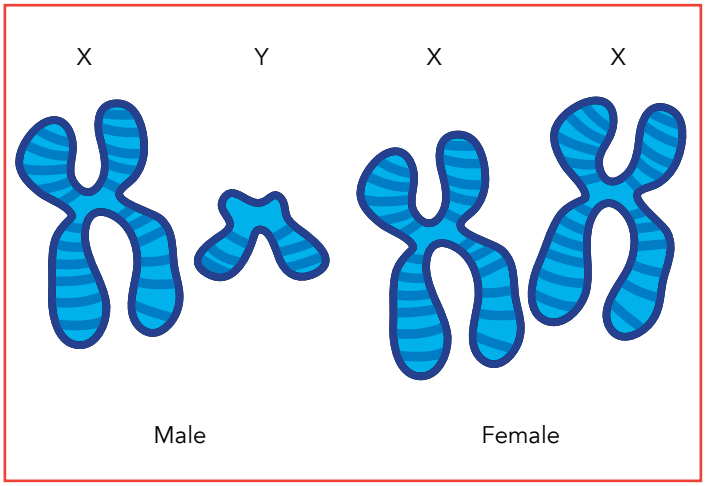
A simplified view of the structure of DNA. You see it does look like a twisted ladder. This type of structure is called a double helix.



This is a picture of a person's chromosomes. As you can see, humans have 23 pairs of chromosomes. The autosomal chromosomes are numbered according to their length. Number one is the longest and number 22 is the shortest. The remaining pair are the sex chromosomes.

However, DNA also contains coded instructions for other things, like the directions for what kind of cell each cell is supposed to be or how busy it is supposed to be. Some scientists have claimed that the DNA that didn't code for proteins was leftover evolutionary junk with no purpose. Bible-believing scientists know that evolution did not create life, DNA, or the human body. Therefore, these scientists predicted that none of our DNA was evolutionary "junk." Now, scientists have begun finding that "junk" DNA really does have a purpose. The double-helix structure of DNA was discovered in 1953, but scientists are just beginning to figure out how much coded information is contained in each molecule of DNA.

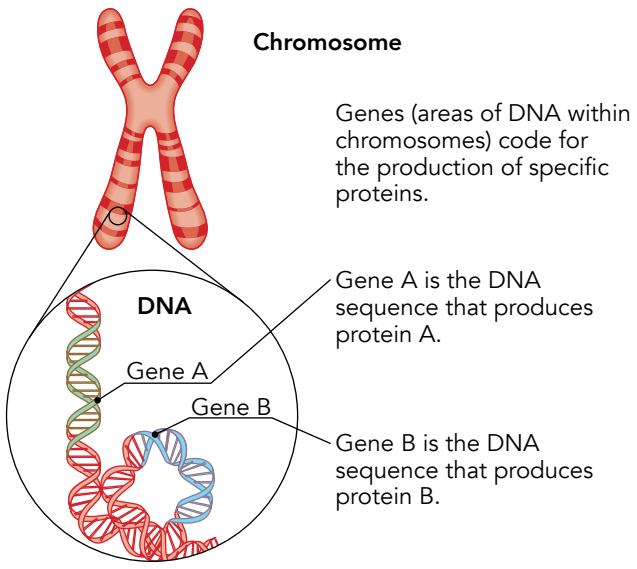
So each strand of DNA is made up of many, many genes. Each gene gives the instructions for building a protein. Proteins are built out of amino acids. Proteins are a kind of biological molecule, and they do much of the "work" in your body. Lots of molecules you may have heard of are proteins. *Enzymes* that perform all the chemical reactions in your cells, *antibodies* that fight infectious invaders, *taste receptors* in your tongue, *collagen* that holds much of your body together, the *actin* and *myosin* molecules that make your muscles contract, the *clotting factors* that make your blood clot, and the transport proteins and identification proteins embedded in your cell



The sex chromosomes determine whether a person is male or female. A person who has an XY pair is male. Those who have an XX pair are female.

TAKING A CLOSER LOOK

Genes and Chromosomes



membranes are all proteins. Each and every protein molecule must be built in a cell, following the instructions from the nucleus.

Each double helix molecule of DNA is carefully organized and packaged into a chromosome. Each *chromosome* is like a section of a huge library where lots of books are stored. A chromosome consists of DNA — like the books — and special proteins that help package it and take care of it — like "shelves." Human beings have 46 chromosomes in each of the body cells.

The DNA in one of your cells would be about 6 feet long if it were stretched out. In just this tiny strand of DNA is contained enough information to fill hundreds of books, and the DNA in just one of your cells contains the coded information to build your whole body!

DNA at Work

So what exactly does DNA do?

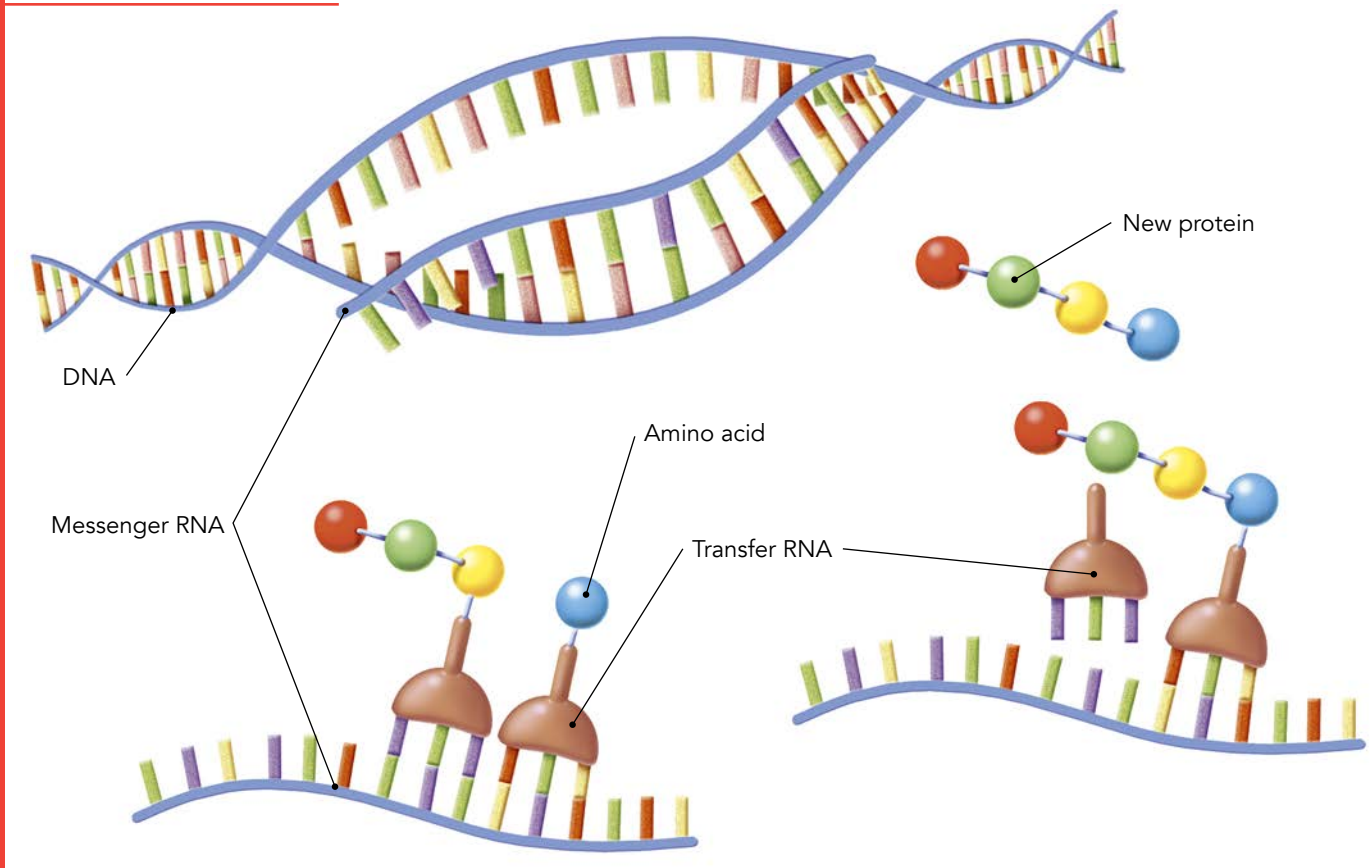
DNA Can Make Proteins

We said that DNA was more than just a string of molecules. It is a complex system of information. This information is used primarily to make the proteins in our body.

Proteins are one of the most important substances in the body. Proteins are made up of long chains of molecules called *amino acids*. For proteins to function properly, the order of these amino acid building blocks must be correct. So there must be a very precise process to make proteins.

TAKING A CLOSER LOOK

Building a Protein



The process of protein making is incredible. DNA uncoils and exposes the gene that contains the necessary instructions. Then the particular segment of the DNA "ladder" that contains the information about the protein splits to expose its nucleotides. (Remember the "words" and "letters"!) Then these nucleotide "words" are read and a special molecule is made. This special molecule is called messenger RNA (mRNA). The mRNA takes the information from the DNA and leaves the nucleus through the pores in the nuclear membrane. Outside the nucleus, the mRNA connects to ribosomes.

Once they're on a ribosome, the mRNA is "read" by another type of RNA, called *transfer RNA* (tRNA). Each kind of tRNA carries the code for a particular amino acid and an attachment for that amino acid. As each segment of the mRNA is read, the tRNA brings the correct amino acid, in the correct order, and the protein is assembled. The ribosome stitches together each protein, folding it carefully so that it will work just right.

What Is "Junk DNA"?

Only a small portion of our DNA actually contains the information that codes for proteins. So what, then, is the purpose of the rest of our DNA?

Many scientists over the last few decades have felt that if any portion of DNA did not actually code for proteins, it had no purpose. For that reason, many scientists began to refer to this part of our DNA as "junk DNA." They felt that these useless regions of DNA were merely left over from our evolutionary past.

However, in recent years, it has been shown that junk DNA is not junk at all. These regions of our DNA are quite active and serve many functions, such as helping switch genes on and off. Every day, researchers are discovering more about how "junk DNA" actually works!

You see, our Master Designer does not make "junk!"

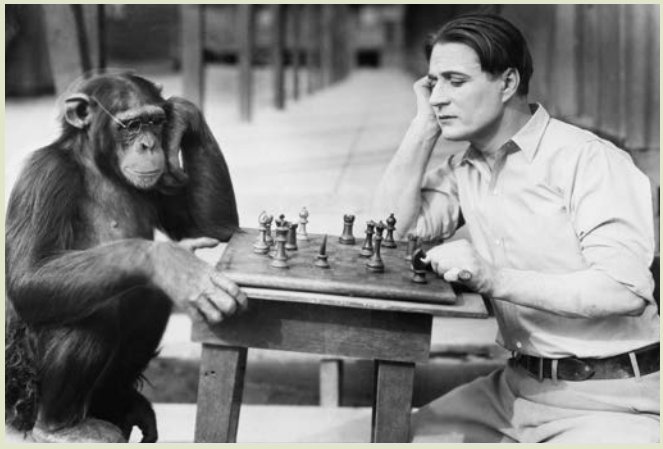
Do Humans and Chimps Have Similar DNA?

It is often said that the DNA of humans and chimps are 98 percent alike. This popular notion has been repeated and repeated so often that most people believe it to be true. Many scientists promote this idea to support their mistaken idea that humans and chimps evolved from a common ancestor a few million years ago. This supposed similarity in DNA is used as "proof" of an evolutionary link between humans and chimps.

Actually, when you really examine the data, you find that the similarity between human and chimp DNA is more like 70 percent. It is nowhere near the 98 percent that some people claim.

Even though there is a 70 percent similarity, that 30 percent difference means an awful lot. Between humans and chimps there are millions and millions of sequences in the DNA that are different. That is obvious as humans and chimps are distinctly different creatures.

So how can we explain the 70 percent of our DNA that is similar to the chimp's? This is simple for the Christian. We understand that all living things have a common Designer, not a common ancestor, as evolution would suggest. This amazing Designer would allow for many design similarities in the creatures he created. These similar features would be reflected in similarities in our DNA.



This process occurs thousand of times each second, and countless proteins are made in our cells each day.

If that were all DNA could do, it would be amazing. But there's more. . . .

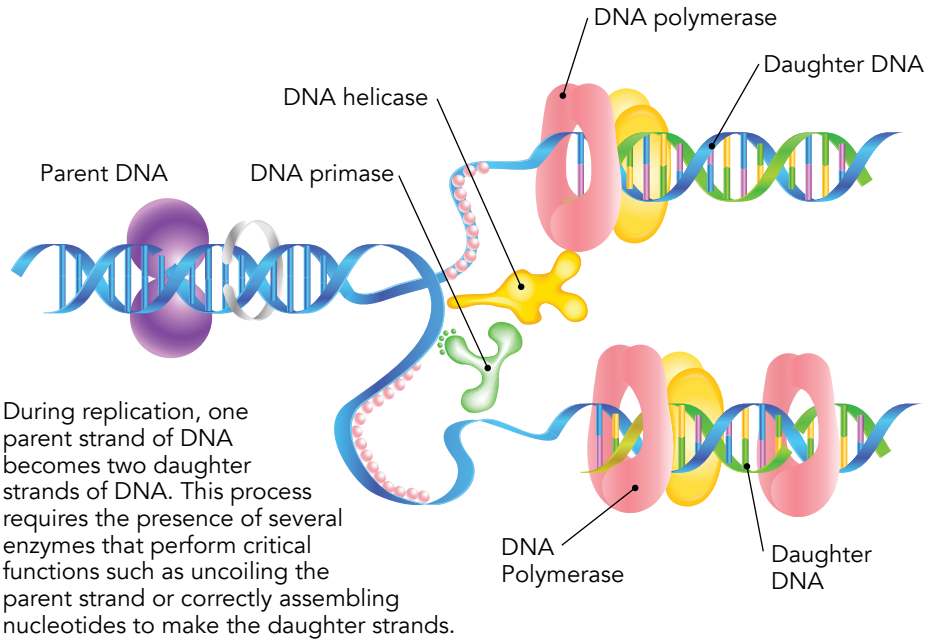
DNA Can Make DNA

Well, DNA is able (with the help of a series of proteins and enzymes) to reproduce itself. By doing this, the information contained in the DNA can be passed on when the cell divides.

It works like this.

TAKING A CLOSER LOOK

DNA Replication



During replication, one parent strand of DNA becomes two daughter strands of DNA. This process requires the presence of several enzymes that perform critical functions such as uncoiling the parent strand or correctly assembling nucleotides to make the daughter strands.

You have seen that DNA looks sort of like a twisted ladder. When it is time for a cell to divide, the membrane around the nucleus temporarily dissolves and the DNA duplicates itself.

First, the DNA in each chromosome uncoils. Then it splits into two strands (almost as if the rungs of the ladder were split in two). With the help of a special set of enzymes, each strand of DNA is copied. When the process is finished, there are two complete sets of chromosomes where there was one set before. Each set of chromosomes is then placed in the newly formed nucleus of a new "daughter cell."

How Cells Divide

While we are on the subject, let's take a closer look at how cells divide. After all, we continually need more cells as we grow and worn-out cells need to be replaced. How does this happen? Let's explore the cell cycle and see how this works! The *cell cycle* is sort of like the life cycle of a cell. There is a time for a cell to focus on its job, whatever that happens to be. And then for most kinds of cells there is a time for it to copy itself and become two "daughter cells."

The part of the cell cycle when a cell is not actually splitting into two cells is called *interphase*. That's when a cell simply does its job, or jobs. During this time, most of the protein-making activity of the cell occurs. The substances that the cell makes for the body's use are manufactured during interphase. Also, during interphase more organelles are made so that there are enough to supply both daughter cells after division. Near the end of interphase, the cell prepares to divide. The DNA in the nucleus duplicates during this part of interphase. For a short period of time, then, the cell has twice its normal amount of DNA — 46 *pairs* of chromosomes rather than just 46 chromosomes! Because these duplicated chromosomes are stuck together, we often use another name to describe them here — a *chromatid*. A chromosome and its copy, stuck together, is called *a pair of sister chromatids*. Remember, the DNA gets duplicated

during interphase so that it is all ready to be split between the two new cells that will be formed during cell division.

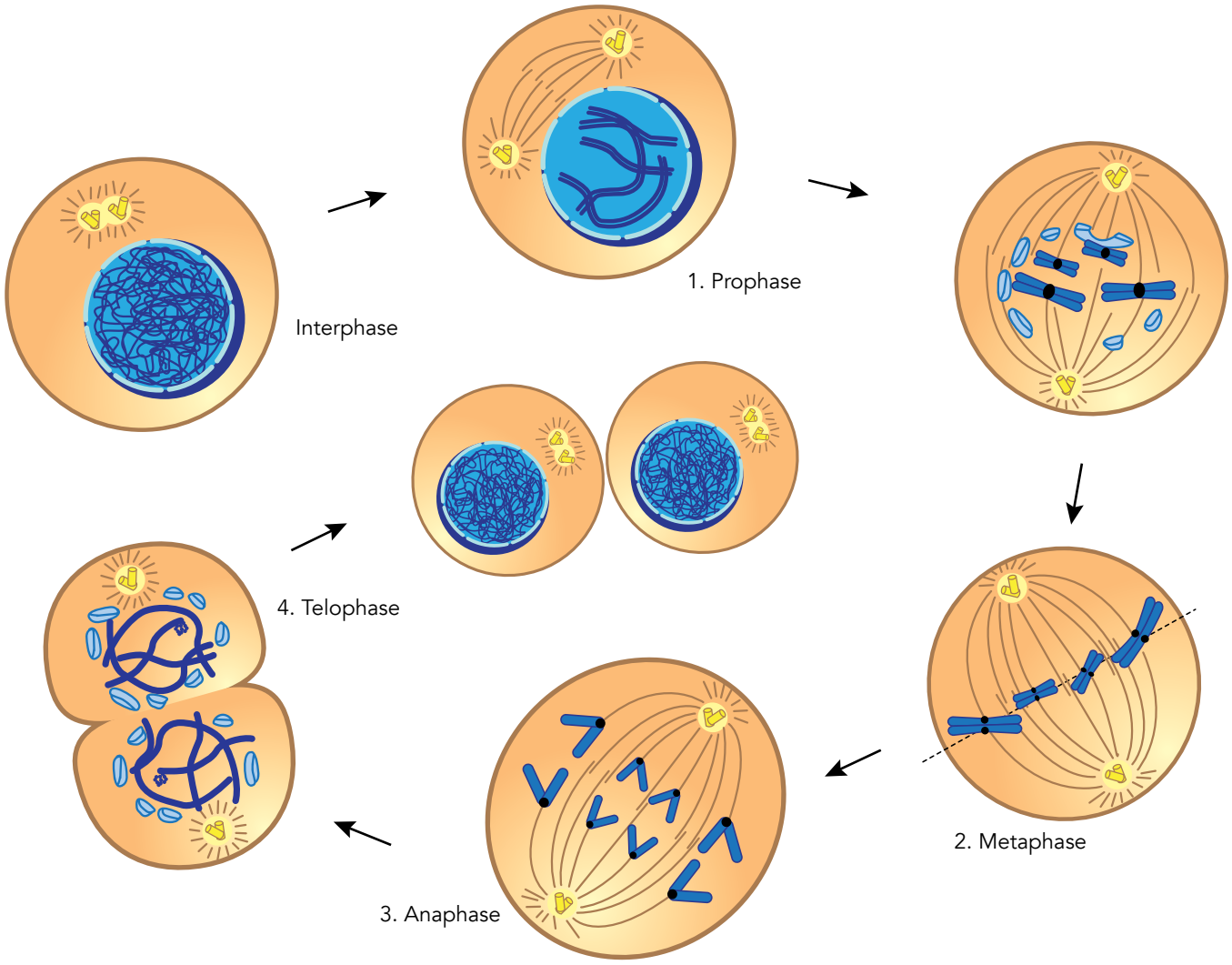
The part of the cell cycle that is directly involved with dividing the cell into two daughter cells is called *mitosis*. So the working phase of a cell's cycle is interphase, and the dividing phase of a cell's cycle is mitosis. Mitosis can be broken down into four steps, called phases (wouldn't you just know it . . .). We will examine each in turn.

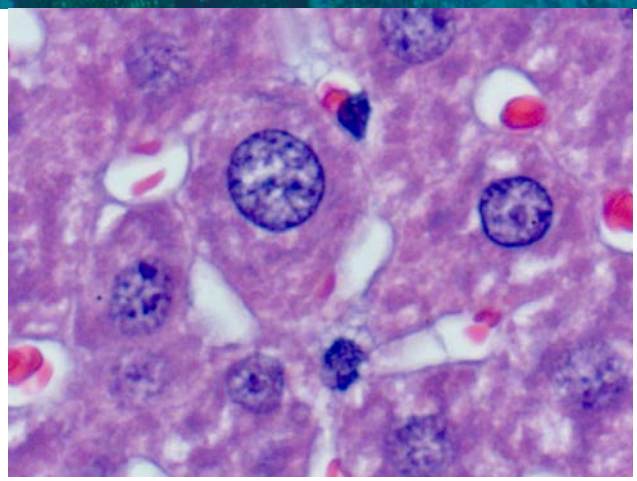
The first phase of mitosis is called *prophase*. Remember that the DNA gets duplicated before interphase is over. That DNA is a tangled mess like spaghetti, however, and it must be sorted out before the chromosomes can be assigned to each daughter cell. During prophase, the DNA coils and tightens, or *condenses*, so that the chromosomes are dark enough to be visible under a microscope.

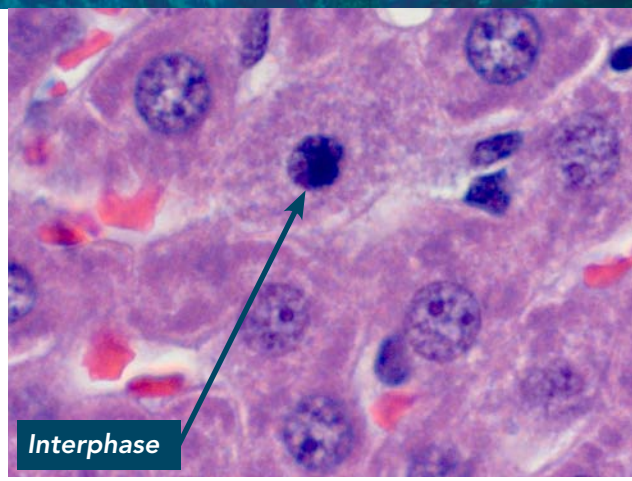
Remember the centrioles in the cytoplasm? Well the membrane around the nucleus dissolves, allowing

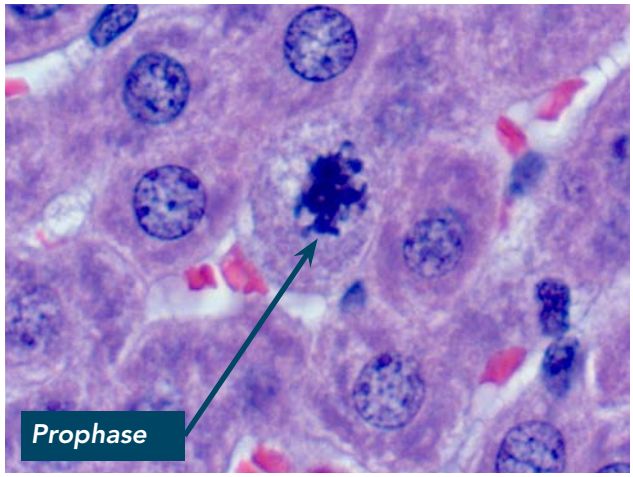
TAKING A CLOSER LOOK

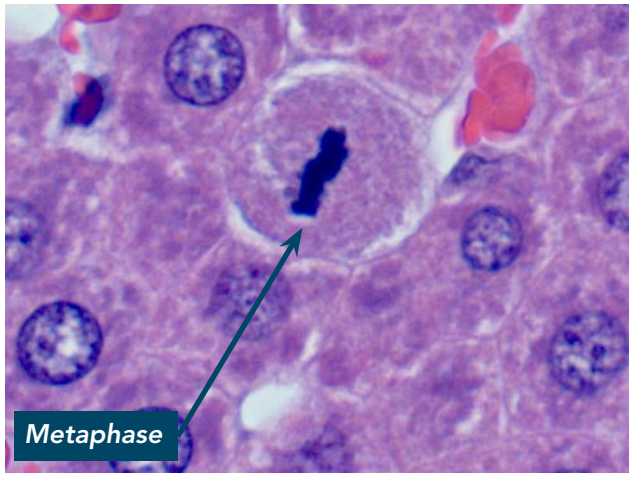
Mitosis

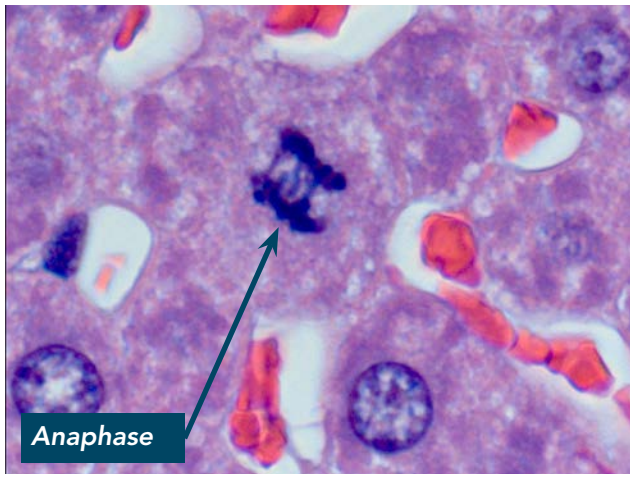


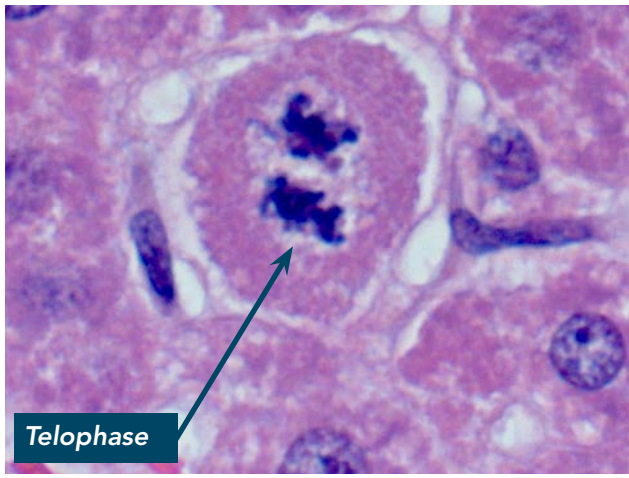


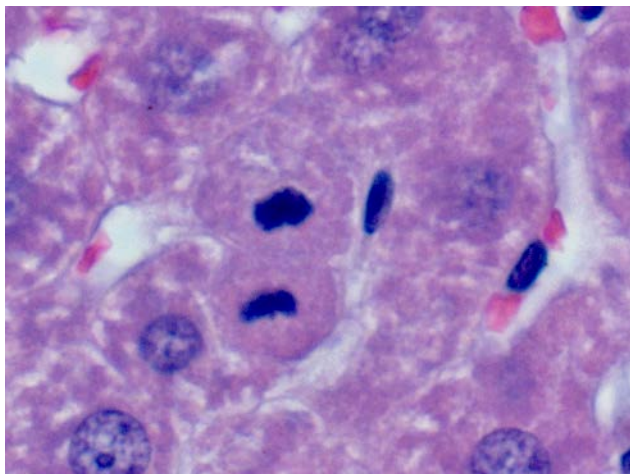


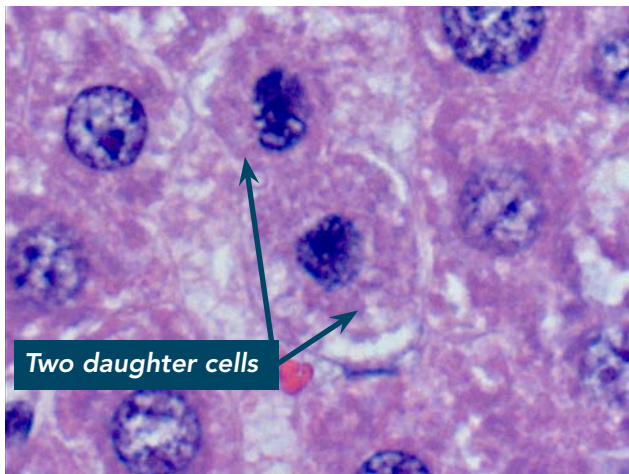












Hepatocytes (liver cells) undergoing mitosis

the centrioles to build a scaffold on which the chromosomes can be organized. The centrioles separate, moving to opposite ends of the cell. A series of microtubules form and anchor to the centrioles. These microtubules attach to the duplicated chromosome pairs — *the sister chromatids* — and begin moving them to the center of the cell.

When all the chromosomes, traveling along the microtubules strung between the centrioles, arrive at the center of the cell, the cell is in *metaphase*. Metaphase is the second phase of mitosis.

The third phase is called *anaphase*. This is the shortest phase of mitosis. At this time, the sister chromatids are pulled apart, each chromatid, or chromosome, moving to opposite ends of the cell. Anaphase ends when the chromosomes reach opposite poles of the cell. Now there is a complete complement of genetic material, enough for one new cell, gathered together. Because the sister chromatids stayed attached to each other until they were all lined up in the middle, and then were pulled apart in opposite directions, each daughter cell should contain identical copies of the genes in the original "parent" cell.

The final phase of mitosis is called *telophase*. During this phase, the chromosomes uncoil and become much less visible. New nuclear membranes form at each end of the cell, encircling the group of chromosomes. Thus, for a brief time the cell has two nuclei (each identical to the original nucleus in the parent cell). Then the cell pinches off in the center, forming two daughter cells.

Moving On . . .

So we have taken a look at the cell and its parts. It is difficult to imagine how people can call the cell "simple," because it certainly isn't. As we continue our journey exploring the human body, there will be many examples of the complex functions performed by cells.

Is DNA Just an Accident?

Many people think so. One common evolutionary belief is that millions of years ago, DNA just formed itself from chemicals, building the complex DNA molecule itself as well as the complex coded messages in it.

You see, many people believe that millions of years ago there was no life on earth. They believe earth's oceans were full of chemicals that, all by themselves, formed the nucleotides from which DNA is made. Then they believe DNA assembled itself from the nucleotides. Yep, they believe that strands of DNA, millions of nucleotides long, just came together . . . in exactly the right order . . . by chance.

But even if that could happen — and nothing in science has ever discovered any way that it could — the evolutionary story still wouldn't make sense. After all, DNA is not just a string of chemicals; it is a very complex information system. So even if DNA could have assembled itself, where did the coded language contained in the DNA come from? Without a source of information and a language code to record that information, the nucleotides in DNA really would just be a string of nonsensical chemicals. You see, information does not come from matter. Information only comes from a higher source of information. And who is the highest source of information?

DNA is not the result of random chance processes. It is another testimony to the magnificent Creator God, the source of all information.

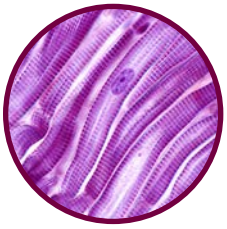
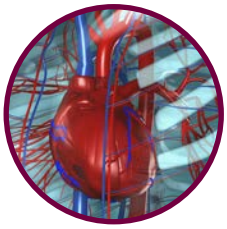
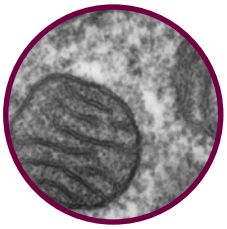
UNIT 2

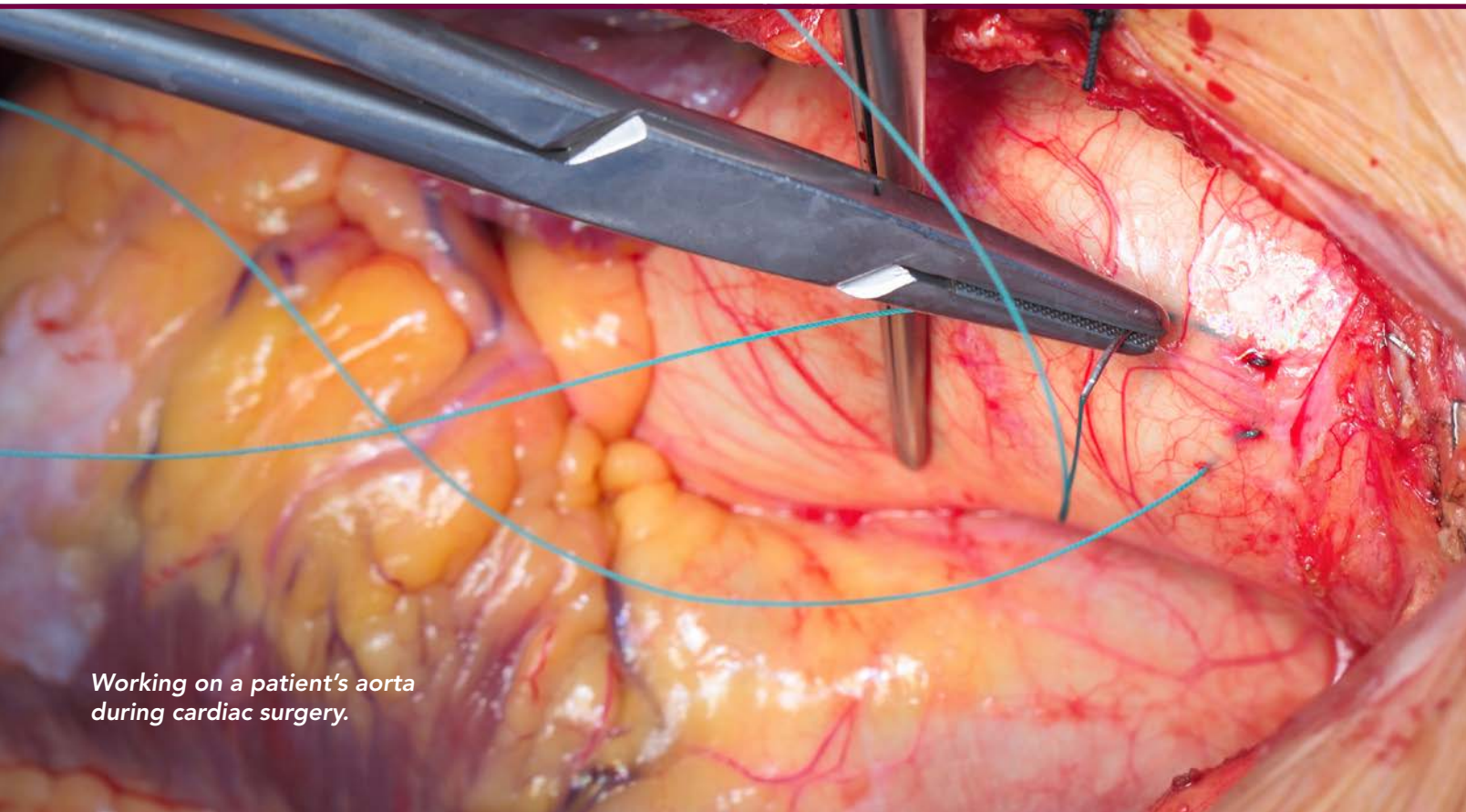
CARDIOVASCULAR & RESPIRATORY SYSTEMS

wonders of the HUMAN BODY

THE HEART

A normal heart is about the size of a person's fist. It is mostly made of **cardiac muscle**. There are two other kinds of muscle — skeletal muscle and smooth muscle. Muscles that enable you to walk or use your hands are examples of skeletal muscles. So is your diaphragm. Muscles that move your food through your digestive tract and the muscles that surround your arteries in order to allow them to influence your blood pressure are examples of smooth muscles. Cardiac muscle cells are designed to communicate efficiently with each other to pass along the electrical impulses that cause the heart to contract. Cardiac muscle cells are packed with **mitochondria**, tiny power-generators that keep the heart muscle continually supplied with energy. Incredibly, the heart only rests for about a fourth of a second during each "heartbeat." After all, the heart cannot afford to take a break!

Working on a patient's aorta during cardiac surgery.

The heart in an average adult pumps around 5 liters of blood every minute when resting. In a trained athlete, the heart can pump up to 33 liters per minute during vigorous exercise. On average, the heart moves 7,200 liters of blood per day. You've only got about 5 liters of blood altogether, so you can imagine that the blood circulates throughout the entire cardiovascular system many, many times in a day.

The heart "beats" on average around 72 times a minute when at rest. A young, healthy person's heart may beat up to 200 times a minute while exercising vigorously.

To keep up this steady pace, the many mitochondria in the muscle cells constantly use oxygen to convert glucose (a form of sugar) to energy. Therefore, those cells must be constantly supplied with oxygen. Without oxygen they cannot contract or even survive. If cardiac muscle cells are damaged by lack of oxygen, they have very little capacity to regenerate or replace themselves. Dead cardiac cells are replaced with scar tissue, but scar tissue cannot help pump. When people eat "heart healthy" foods and do "aerobic exercise," they are trying to keep their heart tissues in good shape to work well for a lifetime.

The Heart, a Workhorse

To really understand how much work the heart does, let's do some calculations.

We will base our calculations on a person with an average heart rate of 72 beats per minute. At rest, the heart pumps roughly 70 mL (2.4 ounces) per beat. So . . . if the heart beats 72 times a minute, that means it beats 4,320 times in an hour, 103,700 times in a day, 37,843,000 times in a year. So, in a person who is 70 years old, for instance, the heart has already beat roughly 2,649,000,000 times. That is almost 3 billion heartbeats (yeah, that's billion, not million)!

The average heart pumps 5 liters of blood a minute.

Looking further, if the heart pumps 70 mL per beat, that means it pumps 5 liters a minute, 302 liters per hour, 7,257 liters (1917 gallons) per day, 2,649,000 liters (699,798 gallons) per year. So the heart of our 70-year-old would have pumped 185,431,680 liters (48,985,000 gallons)!

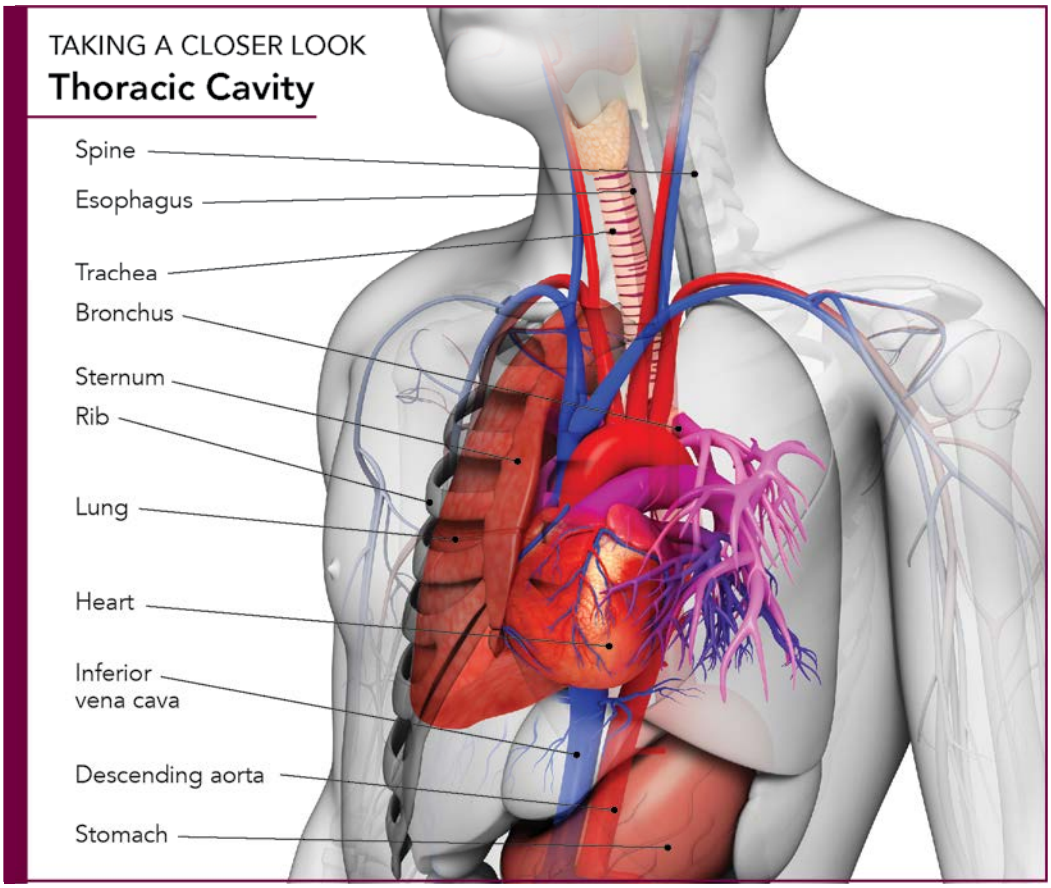
And your heart does all this without taking any time off. It works 24 hours a day, seven days a week. So you would think it wise to keep your heart healthy, right?

Location of the Heart

Your heart is in the center of your chest, under your *sternum*, or breastbone. The heart is shaped sort of like an upside-down pyramid. It is pointed so that its apex is below the middle of your left collarbone. That is why when you put your hand over your heart to say a pledge, you place your hand a little to the left of the sternum, because this is where the "beats" of the heart can be easily felt.

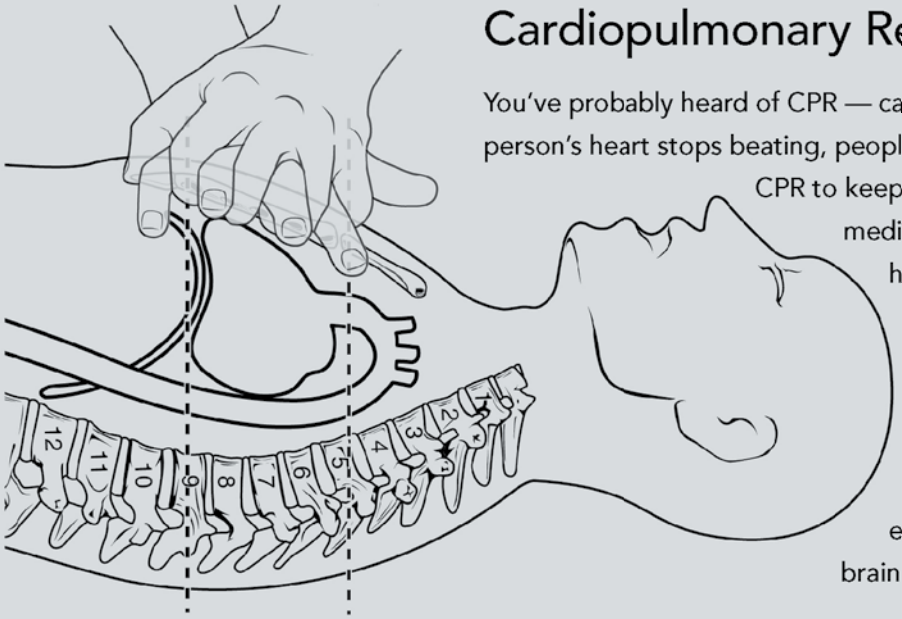
Your thoracic cavity, or chest cavity, has three main compartments. The left and right are occupied by your lungs. Your heart is in the middle one — the *mediastinum*. (The word comes from the Latin word

for "middle.") The heart isn't alone in this space. Also in the mediastinum are some important nerves, the large blood vessels (and lymphatic vessels) that enter and leave the heart, and the esophagus and trachea. The esophagus carries the food you swallow to your stomach. The trachea carries the air you breathe to your lungs. There is a lot of traffic in the mediastinum, and with the ever-beating heart the mediastinum is a busy place!



If we look at the mediastinum from front to back at the level of the heart, we'd see the sternum in front, then the heart. Behind the heart is the esophagus, but not the trachea. The trachea splits into the right and left bronchi before it reaches as low as the heart. Behind the esophagus is the descending aorta, and then the spine.

Then, below the mediastinum is the diaphragm. The diaphragm is a large sheet of skeletal muscle that separates the chest cavity from the abdominal cavity.



Cardiopulmonary Resuscitation (CPR)

You've probably heard of CPR — cardiopulmonary resuscitation. When a person's heart stops beating, people trained in this form of first aid can start CPR to keep the blood circulating until emergency medical help can arrive. Now that you see the heart is really between the sternum and the spine — and not way off to the left — you can see how CPR works. With proper training, a person can press on the chest to squeeze the heart between the sternum and the spine, forcing enough blood out of the heart to keep the brain and body supplied with some oxygen.

The Pericardium

As the heart pumps, it constantly rubs against the other structures in the mediastinum. You might think that would create a lot of friction. Friction would generate heat and lots of wear and tear on the outer surface of the heart. To prevent this, God designed the heart with its own lubrication system. (After all, blisters from friction like you get on your feet wouldn't do your heart any good!)

Like many other organs that we'll learn about, the heart grows inside a pushed in, double-layered, balloon-like sac during embryonic development. Imagine a slightly inflated balloon containing a tiny bit of lubricating fluid. Now imagine pushing your fist into the balloon so that two layers of rubber are against your fist. Try it yourself with a few drops of cooking oil inside a slightly inflated balloon. Is your hand inside the balloon? Not exactly. But when you wiggle your fist, the oiled rubber surfaces should slide smoothly against each other. The oil prevents friction.

Your heart is inside just such a sac, the *pericardium*. *Peri* means "around." This sac goes around the heart. The *pericardial sac* has an outer layer called the *fibrous pericardium* and an inner layer called the *serous pericardium*.

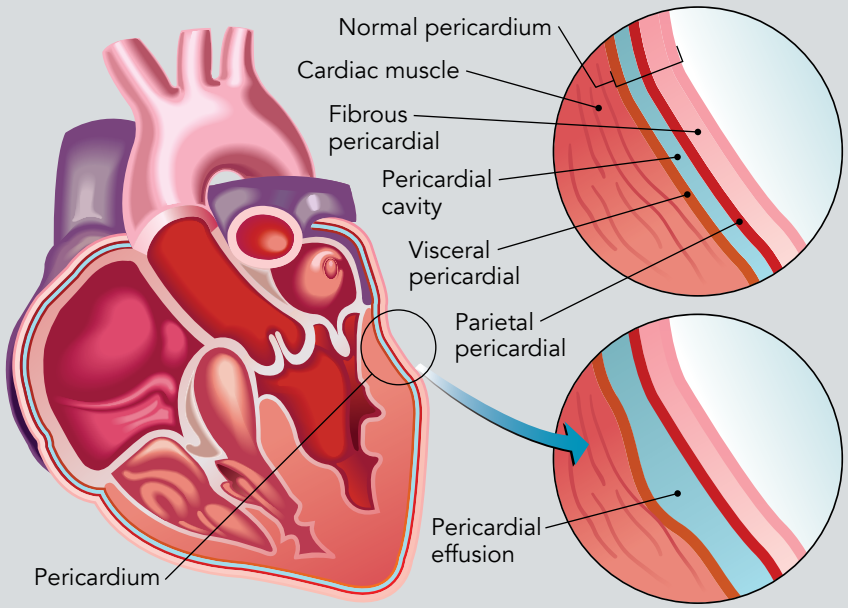
The fibrous pericardium is composed of tough, inelastic connective tissue. It serves to protect the heart, and to hold the heart in position in the chest.

The serous pericardium itself is made of two layers. The inner layer of the serous pericardium is called

Pericarditis

Occasionally, the pericardium can become inflamed. This condition is known as pericarditis.

It can occur suddenly, and it causes chest pain that is quite often severe. This pain sometimes radiates to the left shoulder and can be mistaken for a heart attack. The inflammation can be the result of a viral, bacterial, or fungal infection. Other causes include malignancy (cancer), heart attack, and trauma.



Some cases of pericarditis are quite mild and are treated with medication that controls inflammation. Other cases can be more aggressive and cause thickening of the pericardial sac, which can limit the movement of the heart. At times, the inflammation is severe enough that fluid begins to collect inside the pericardial sac. (This is called a **pericardial effusion**). Small amounts of fluid are easily tolerated and often resolve with treatment. However, in certain cases the amount of fluid that accumulates in the pericardial sac is enough to compress the heart and alter its ability to pump blood. This dangerous condition is a medical emergency known as **cardiac tamponade**. It is most often treated by inserting a needle into the pericardial sac and draining the fluid.

the visceral pericardium. The *visceral pericardium* is a thin layer stuck to the outer surface of the heart, just like the inner layer of balloon rubber was against your fist. The outer layer of the serous pericardium is called the *parietal pericardium*. The parietal pericardium is fused to the fibrous pericardium.

The visceral pericardium secretes a small amount of fluid, known as *pericardial fluid*, that provides lubrication between the visceral pericardium and the parietal pericardium. This fluid minimizes friction as the heart beats. You see, our Master Designer thought of everything!

If we peeled back the pericardium, we'd see the great vessels emerging from the upper part of the heart. The upper end of the heart is called the *base*, even though it is on the top, because it forms the broader part of the pyramid-like heart's shape. (The *apex* is the pointy bottom end.) Peeling back the pericardium would also reveal the coronary arteries and the cardiac veins running across the surface of the heart and sending their smaller branches down into the muscle of the heart.

The Layers of the Heart

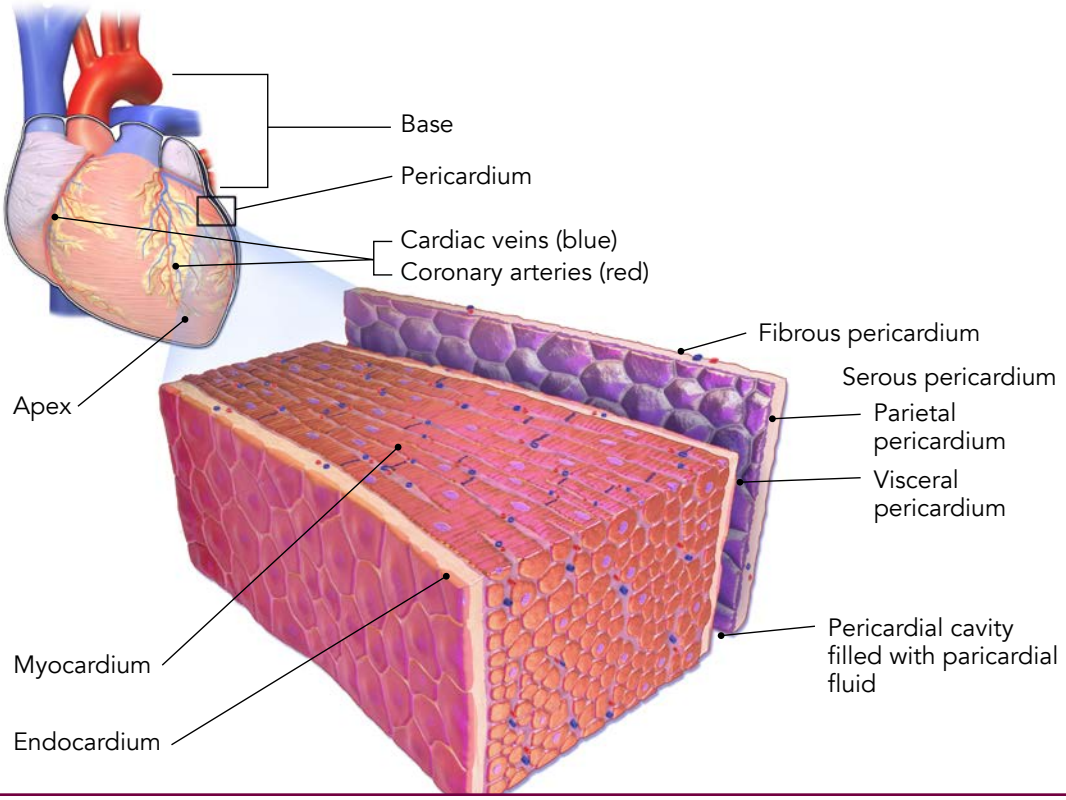
The wall of the heart consists of three layers: the *epicardium*, the *myocardium*, and the *endocardium*. Now you can see how thinking of anatomical names as word puzzles can help you! *Peri*, as in "pericardium," means "around," and the pericardium surrounds the heart. *Epi* means "outer," *myo* means "muscle," and *endo* means "inner." And of course *cardium* means "heart"! Therefore, these words are names for the layers of the heart itself.

Remember, we said that the pericardium consists of the outer parietal pericardium and the inner visceral pericardium, which is plastered to the surface of the heart. The outermost layer of the heart is actually the visceral layer of the pericardium. Where this membrane contacts the heart it is called the *epicardium*. It is made mostly of connective tissue and provides a protective covering for the surface of the heart.

The middle layer forms the bulk of the heart and is called the myocardium. As you might expect, knowing that *myo* means "muscle," this layer

TAKING A CLOSER LOOK

Pericardium and Layers of the Heart



is primarily cardiac muscle. The myocardium makes up about 95 percent of the mass of the heart. This is the layer that is responsible for the contraction of the heart. There is also some connective tissue in the myocardium. This connective tissue helps hold the cardiac muscle fibers in proper orientation so they can work together to make the heart contract properly.

The innermost layer of the heart wall is a smooth, thin lining called the endocardium. The *endocardium* lines the heart chambers and covers the valves of the heart. It also extends into the blood vessels attached to the heart. Because it is very smooth, the endocardium minimizes friction as blood passes through the heart. Healthy endocardium keeps blood from clotting as it moves through the heart.

Cardiac Muscle

Let's take some time to examine the myocardium in more detail.

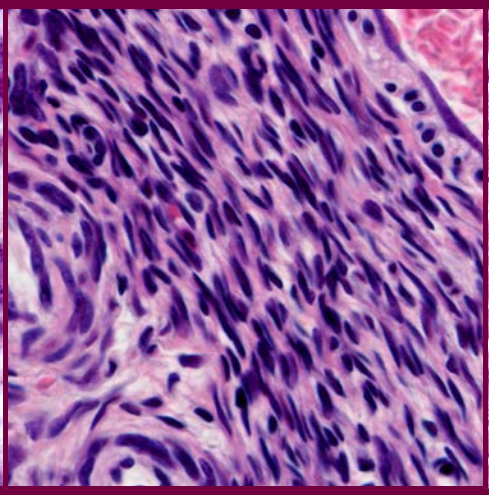
You have learned that there are three types of muscle: skeletal muscle, smooth muscle, and cardiac muscle. The myocardium is mainly composed of cardiac muscle. As we will see, cardiac muscle is both similar to and different from skeletal muscle.

Like skeletal muscle, cardiac muscle is striated. However, the striations are not as easily seen in cardiac muscle. Cardiac muscle cells are shorter and fatter than skeletal muscle cells. Also, cardiac muscle cells branch and connect with one another in a somewhat irregular pattern. Like all cells, cardiac muscle cells are surrounded by a plasma membrane (also called a cell membrane). At the end of cardiac

Muscle Tissue Types

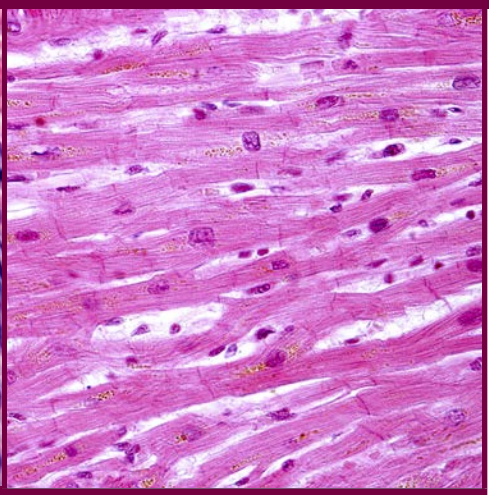
Skeletal Muscle Tissue

Skeletal muscle is attached to the bones of the skeleton. When it contracts, it allows us to move our arms and legs, or grasp something with our hands, or smile when we're happy. It has a structure that is distinct from other types of muscle.



Smooth Muscle Tissue

Smooth muscle is found in the walls of most of the hollow organs of the body. For example, it is found in the walls of our digestive tract where it helps push our food as it is digested. Smooth muscle is found in blood vessels, the urinary tract, the respiratory tract, the prostate, among other places. Smooth muscle is not under our direct control, and is sometimes referred to as involuntary muscle.



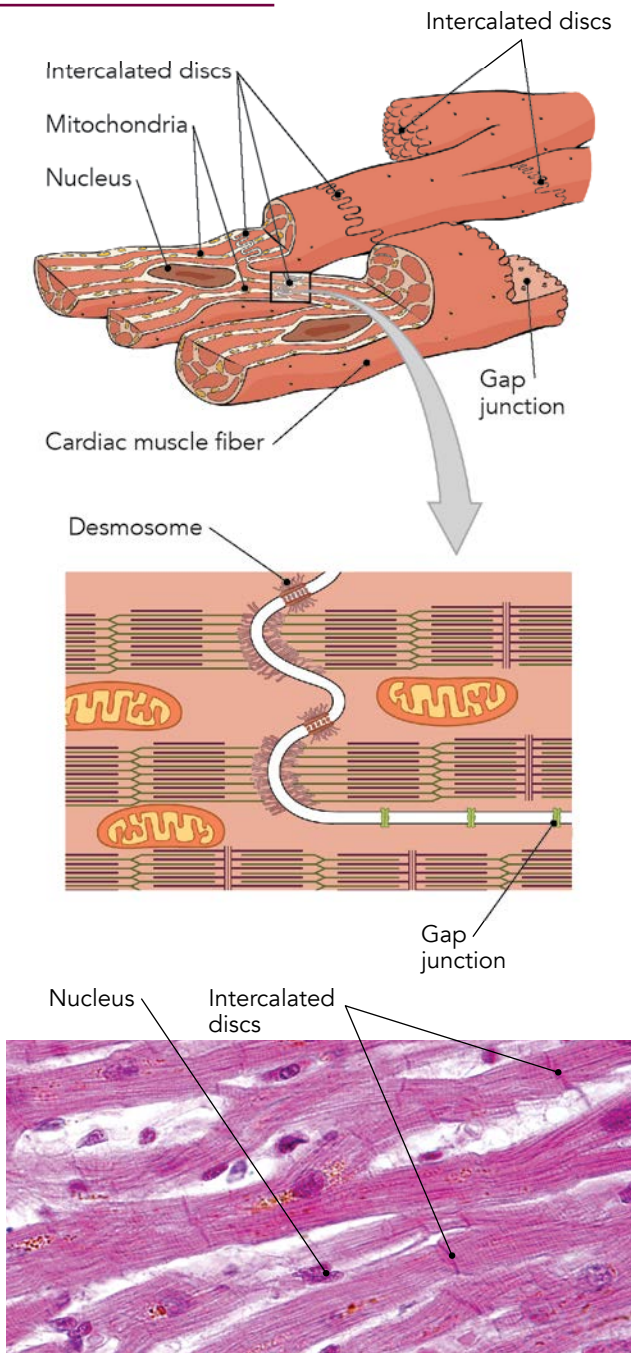
Cardiac Muscle

The third type of smooth muscle is cardiac muscle. It is found only in the walls of the heart. This type of muscle is also an involuntary muscle.

muscle cells are thick areas of the surrounding plasma membrane called *intercalated discs*. These intercalated discs form a special interlocking connection between the cells. Each intercalated disc contains two special structures that are very important to the proper function of cardiac muscle. One of these is called a *desmosome*, which helps hold the muscle fibers together as they contract. Also found in the intercalated disc are *gap junctions*. The junctions provide a route for electrical signals to be transmitted from muscle cell to muscle cell. These gap junctions ensure efficient transmission of electrical signals, which allows the cardiac muscle to contract in a coordinated fashion.

TAKING A CLOSER LOOK

Cardiac Muscle



Cardiac muscle also differs from skeletal muscle in the number of mitochondria it contains. Mitochondria generate energy for the cell, and even though skeletal muscles need energy, they don't need nearly as much as the heart's muscle. Mitochondria make up about 25 percent of the volume of a cardiac muscle cell. In contrast, mitochondria account for only about 2 percent of the volume of a typical skeletal muscle cell. This, of course, makes perfect sense when you think about it, right? A large part of the time a skeletal muscle is at rest so its energy needs would be low. On the other hand, cardiac muscle is constantly active, constantly beating. The much greater number of mitochondria would give the cardiac muscle the energy production necessary to support this high level of activity.

Skeletal muscle responds to the voluntary control of your nervous system. Your conscious command can make skeletal muscle contract. On the other hand, cardiac muscle is involuntary. It does not require conscious command to contract. It is not under your conscious control. This is really the only way the heart could work. None of us would live very long if we had to think about every heartbeat!

Two Pumps in One

We said the heart is a pump, but really, it is two pumps. The heart is two pumps operating side by side, simultaneously. The right side of the heart pumps blood to the lungs. The left side of the heart pumps blood to the brain and the body. One heart, two pumps.

The heart's two pumps must be perfectly synchronized. Deoxygenated blood has given up most of its oxygen supply to the body's tissues. This deoxygenated blood returns to the right side of the heart and gets pumped out to the lungs. There it will be resupplied with oxygen. At exactly the same time, oxygenated (oxygen-rich) blood returns to the left side of the heart from the lungs and gets pumped out to the brain and body. If there is even the slightest mismatch between the two sides, problems can develop quickly. A healthy heart is perfectly balanced and keeps blood moving in a coordinated fashion, shuttling it first through the right-side pump, then to the lungs, and then through the left-side pump.

Since the pump on the right circulates blood to the lungs, the right-sided circulation is called the *pulmonary circulation*. *Pulmonary* means "lung." The pump on the left sends blood to all the body's other *systems*, so the left-sided circulation is called the *systemic circulation*.

We will learn the names for the large blood vessels entering and leaving the heart, but we'll first need to learn the difference between an artery and a vein. An *artery* is the name given to a blood vessel in which blood moves *away* from the heart. When blood leaves the heart to go to the lungs, it travels in arteries. And when blood leaves the heart to go to the body and brain, it also travels in arteries. Of course, the blood going to the lungs is deoxygenated, and the blood going to the body is oxygenated. So the blood in arteries can be carrying lots of oxygen or very little.

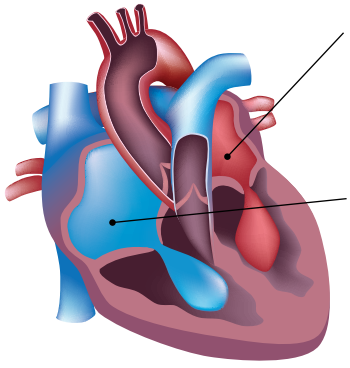
Vessels carrying blood *toward* the heart are called *veins*. Now you know that both oxygenated and deoxygenated blood can be carried in arteries. What about veins? The same is true. Some large veins (called *vena cavae* — a word that means big "cavernous" veins) carry deoxygenated blood back to the right side of the heart. And some other large veins (*pulmonary veins*) carry freshly oxygenated blood from the lungs to the left side of the heart. So, as with the arteries, veins can be carrying blood rich in oxygen or blood with very little.

Confusing, right? Well, we will try and give you a hand.

You may have seen drawings of the circulatory system and noticed that some of the blood vessels are colored red and some blue. Artists often draw the blood vessels this way to show you which vessels carry oxygenated blood and which vessels carry deoxygenated blood. Oxygenated blood has recently passed through the lungs to pick up a full load of oxygen using the hemoglobin in its red blood cells. Deoxygenated blood has already dropped off most of its oxygen supply in the tissues and is ready to be sent back to the lungs to pick up some more. All blood is red, but oxygenated blood is a brighter red and deoxygenated blood has a more purplish-red color. Even though deoxygenated blood is not really

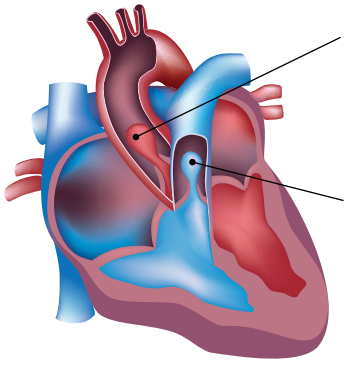
TAKING A CLOSER LOOK

Pulmonary vs Systemic Circulation



Systemic circulation - The left side pump fills with oxygen-filled blood from the lungs.

Pulmonary circulation - The right side pump fills with oxygen-depleted blood from the body.



Systemic circulation - The left side pump pushes the oxygen-filled blood to the body.

Pulmonary circulation - The right side pump pushes the oxygen-depleted blood to the lungs.

blue, the blood vessels carrying it are most often illustrated as blue to help people see the difference more clearly.

Chambers of the Heart

The human heart has four chambers.

Two chambers belong to the pump on the right — the right atrium and the right ventricle. These chambers are responsible for circulating blood to the lungs. Again, this is known as the pulmonary circulation.

The other two chambers belong to the pump on the left — the left atrium and the left ventricle. These chambers work to push blood out to the body tissues to supply them with oxygen and nutrients. This is the systemic circulation.

The word *atrium* means "entry room" or "receiving room." The *atria* (plural of atrium) collect blood as it returns to the heart. Blood that has already dropped off most of its oxygen supply enters the right atrium. (This is *deoxygenated* blood.) The left atrium collects oxygen-rich blood returning from the lungs.

Do arteries or veins bring this blood to the heart's atria? Hopefully, you said, "veins." Remember, *veins* bring blood *to* the heart. The veins that bring blood from the lungs to the left atrium are called *pulmonary* veins because they *come from the lungs*. The veins that bring blood back from the brain and the body are called *vena cavae*. The big vein from the upper body and brain is called the *superior vena cava*, and the big vein from the lower body is called the *inferior vena cava*. The name *vena cava* means "hollow vein," and *cavae* is the plural of *cava*. The words *superior* and *inferior* mean "upper" and "lower," respectively.

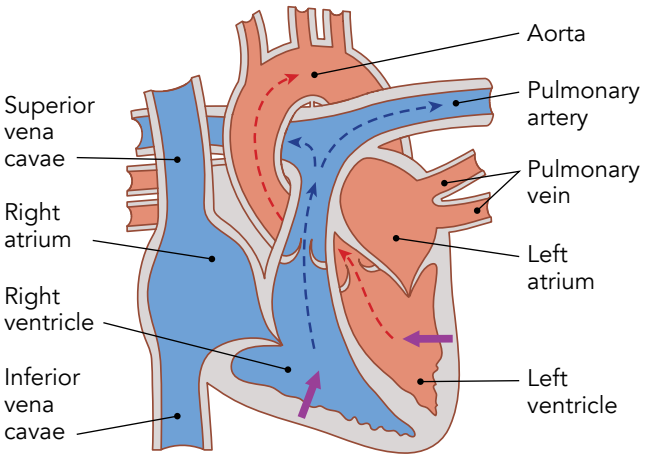
What kind of blood would you find in the superior and inferior vena cavae?[1] How about the pulmonary veins?[2] See, it's not really all that hard, is it?

The right and left atria collect blood and then send it on to the ventricles. As the atria fill, the pressure within the atria rises as a result of the increasing amount of blood. Then, when the ventricles relax, this pressure starts pushing blood from the atria

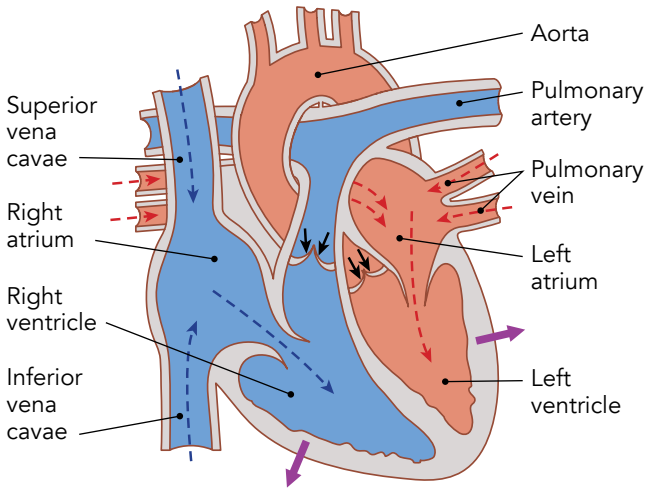
1 Deoxygenated blood returns to the heart via the superior and inferior vena cavae.
2 Oxygenated blood returns to the heart from the lungs through the right and left pulmonary veins.

TAKING A CLOSER LOOK

Chambers of the Heart



Ventricular Systole



Ventricular Diastole

into the ventricles through the valves connecting them even before the atria contract. Just before the ventricles pump, the atria squeeze to push an extra bit of blood into the ventricles. After the atria empty, it's time for the ventricles to squeeze hard and push blood out to the lungs and body.

The right ventricle is part of the pump on the right, and it pushes oxygen-poor (deoxygenated) blood out through the pulmonary artery to the lungs. The left ventricle is part of the pump on the left, and it pushes blood out through a large artery called the *aorta*. This oxygen-rich (oxygenated) blood is sent through the aorta's branches to the brain and to the entire body.

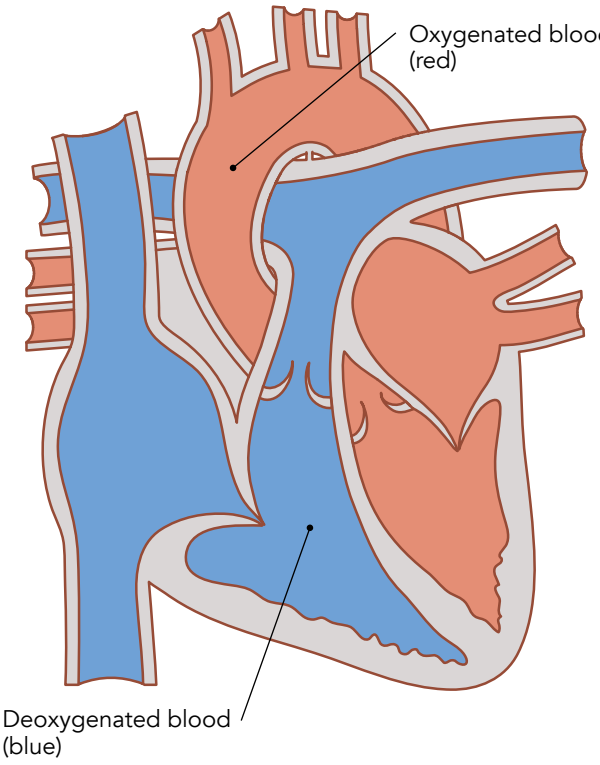
The walls of the ventricles are made of thicker muscle than the atrial walls, but the ventricles are not the same. Remember, the right and left sides must always have the volume of blood they pump in and out perfectly matched. Even though this balance must be maintained, the two ventricles are different from one another. You see, the right ventricle only has to pump blood to the lungs, a short distance away. And it doesn't take much pressure to push blood through the pulmonary circulation. In contrast, the left ventricle pumps blood out to the entire body. It must push blood through the miles and miles of blood vessels that make up the systemic circulation. The pressure in the systemic circulation is much higher than in the pulmonary circulation. Therefore, the muscle of the left ventricle is much thicker than that of the right ventricle. In fact, the muscular wall of the left ventricle is typically two to three times thicker. This thick muscle allows the left ventricle to generate the great force needed to force blood through the entire body.

Pattern of Blood Flow

Now that you've learned about the four chambers of the heart and the major vessels entering and leaving the heart, you should be able to trace the path of blood as it travels through this marvelous double-pump. Oxygen-poor blood enters the right atrium from the superior and inferior vena cavae. At the same time, oxygen-rich blood is brought by the pulmonary veins to the left atrium. (There are four pulmonary veins, two from the left lung and two from the right lung.) Blood flows from the right atrium into the right ventricle. At the same time, blood flows from the left atrium into the left ventricle.

TAKING A CLOSER LOOK

Oxygen-rich vs Oxygen-poor Blood



After each atrium contracts, pushing that last little bit of blood into the ventricles, the ventricles give a mighty squeeze. Oxygen-poor blood from the right ventricle goes out through the pulmonary artery. The pulmonary artery soon branches to the right and left, and each of these subdivides and branches many times to carry blood to the lungs. At the same time, the left ventricle pushes oxygen-rich blood out of the heart through the aorta. The aorta goes upward, sends off some branches, and then arches downward

where it continues as the descending aorta to carry blood to the lower body.

Be sure you understand that the right and left pumps fill and then contract simultaneously. Then see if you can trace the path of a red blood cell as it enters the heart, travels to the lungs, returns to the heart, and is sent out through the aorta. Then see if you can do it without looking at the illustrations. If you don't get it right away, relax. It will be easy for you in no time.

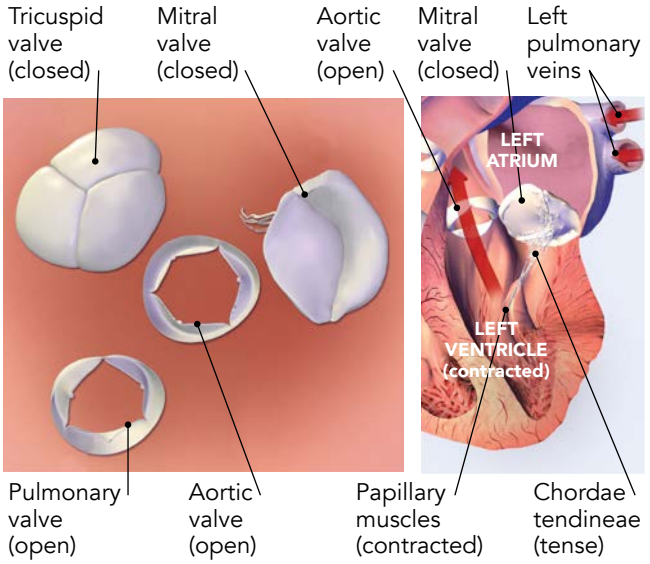
Heart Valves

You know that most of the rooms in your home have doors. It is obvious why those doors are there. But are there rooms that don't have doors? Those rooms were designed for a reason. The rooms that have no doors allow access in and out much more easily, right? On the other hand, you've probably seen businesses that have one-way doors — separate doors for going in and for going out.

Which design do you think would work best for the heart's "rooms," its chambers? What would happen to the blood in the ventricles when the ventricles squeezed if the heart's rooms had no doors? If you said some blood would go backward into the atria, you see the problem. The ventricles would waste much of their effort if part of the blood went back-

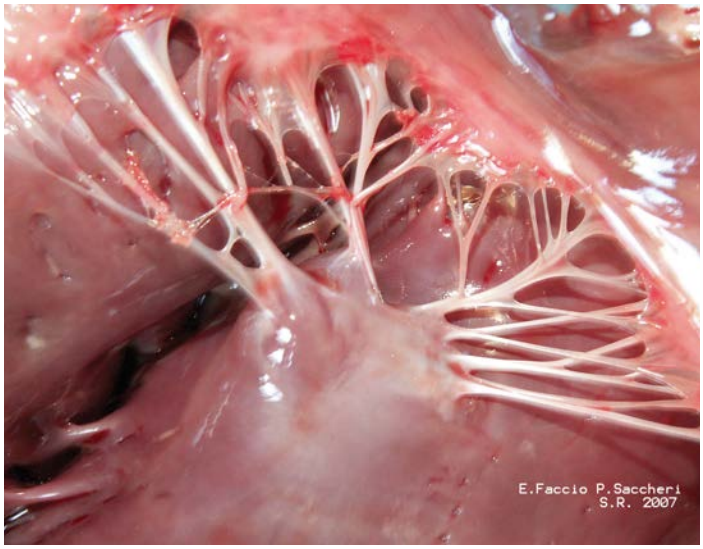
TAKING A CLOSER LOOK

Valves of the Heart

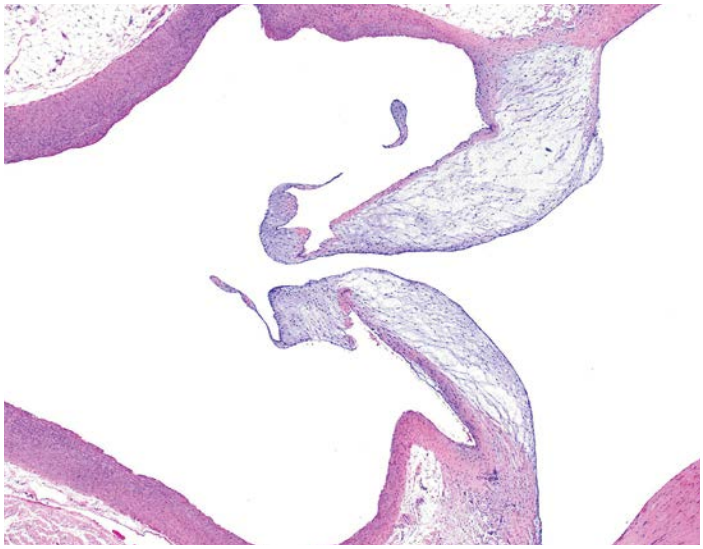


ward. To keep this from happening, the chambers are separated by one-way valves. A valve must allow the blood to flow freely in one direction but then shut to stop any back-flow.

Blood passes from the right atrium into the right ventricle through the *tricuspid valve*. Blood passes from the left atrium into the left ventricle though the *bicuspid valve*, also known as the *mitral valve*. Notice that both of these valves have "cusp" in the



Chordae tendineae



Aortic valve

name. A *cusp* is like a little parachute that fills with blood from the ventricle under pressure, distending the cusp back toward the atrium as the ventricle squeezes. The cusps keep the blood from flowing back into the atria. The tricuspid valve consists of three ("tri") cusps, and the bicuspid (mitral) valve has two ("bi") cusps. The name *mitral* is used for the bicuspid valve because the two cusps look a little like a bishop's headdress, called a miter.

If these cusps were not secured to the walls of the ventricles, the high-pressure blood filling them would push back into the atria. The cusps are therefore tethered to the ventricular walls. The ties that bind these cusps to the ventricular wall are called *chordae tendineae*. This Latin name means "heart strings." As the high-pressure blood distends the cusps, it is kept from being pushed back into the atria by these little tethers.

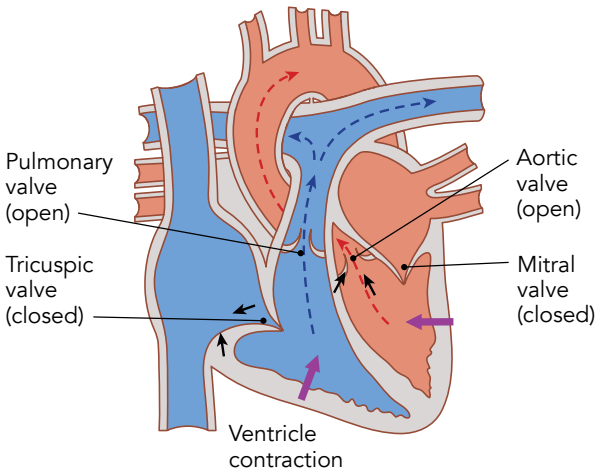
Heart Strings

Already you can probably see the great design in this arrangement. But there could be a problem: when the ventricles contract, they shrink. And as they shrink, the chordae tendineae (heart strings) tethering the cusps must somehow get shorter. Otherwise, the cusps would push back into the atria! God designed an amazing feature to keep the chordae tendineae tight as the ventricles shrink. These little cords are attached to the ventricular walls by tiny papillary muscles. As the ventricles contract, the papillary muscles also contract, being perfectly coordinated with the ventricles. These muscles keep the chordae tendinae taut and stabilize the cusps of the valves. (No way this is just a cosmic accident, right?).

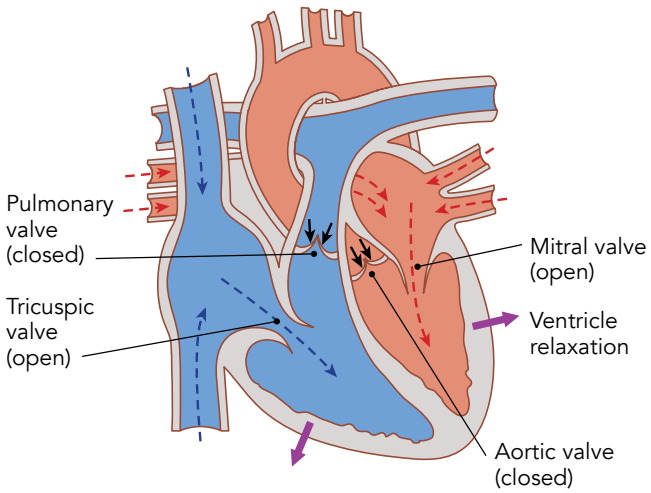
The heart's valves do not require a doorman to close them. The pressure of the blood inside the ventricles pushes them shut. We could even say the pressure makes them slam shut. But they make no noise. You've probably heard that the heart makes a "lub-dub" sound with each beat. The "lub" sound comes from the closure of the tricuspid and mitral valves, but it isn't the "slamming shut" that makes the "lub." It isn't even the silent squeezing of the ventricles that makes the "lub" sound. The "lub" comes from the turbulence of the blood rushing against the valves. (Think of the sound a wave makes as it crashes into a beach. Moving liquids, whether water

TAKING A CLOSER LOOK

Heart Sounds



The first heart sound (S1), is caused by the closure of the mitral and tricuspid valves at the beginning of ventricular contraction (systole)



The second heart sound (S2), is caused by the closure of the aortic and pulmonary valves at the end of ventricular systole

or blood, are powerful!) Of course, since the "lub" happens when the tricuspid and mitral valves close, it may be easier for you to think of the "lub" as the result of the doors slamming shut.

When the blood leaves the heart through the pulmonary artery and the aorta, another set of valves is needed to keep it from flowing backward into the ventricles. If any blood flowed backward, the ventricles would have to do extra work by pushing it out again with the next beat. Such an arrangement would not be very efficient! (In fact, this very problem happens when valves are damaged, as we will discuss later.)

These valves — the valves guarding the exit from the ventricles — are called *semilunar valves*. As you know already, *lunar* means "moon," so *semilunar* means "half-moon-shaped." Each "ventricular exit" valve consists of three of these crescent-shaped cusps. The semilunar valve between the right ventricle and the pulmonary artery is called the *pulmonary valve*. The semilunar valve between the left ventricle and the aorta is called the *aortic valve*.

The semilunar valves do not have any chordae tendineae. The pressure in the pulmonary artery and the aorta is not high enough to force them backward into the ventricles, so none are needed.

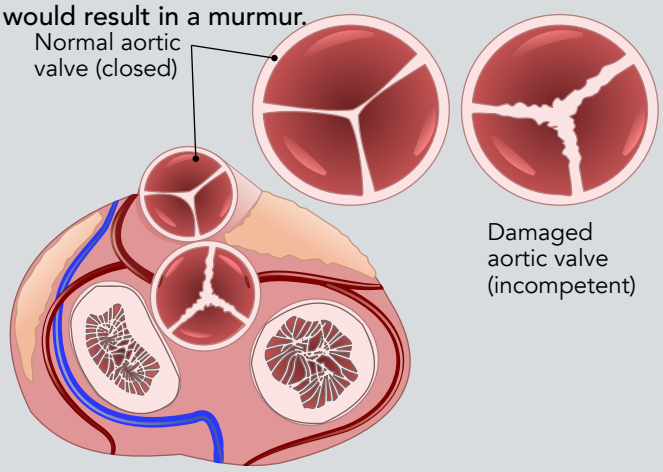
Just as the tricuspid and mitral valves needed no doorkeeper, the pulmonary and aortic valves need no doorkeeper to open or shut them. Fluid pressure does the job. When the ventricles begin to contract, the pressure they generate slams the tricuspid and mitral valves shut. The pressure in the ventricles then quickly rises, forcing the pulmonary and aortic valves to silently open. The blood in the ventricles rushes out through the open valves. When the ventricles have finished their contraction, the semilunar cusps swing closed and balloon slightly toward the ventricles, filling with blood but not leaking backward into the ventricles.

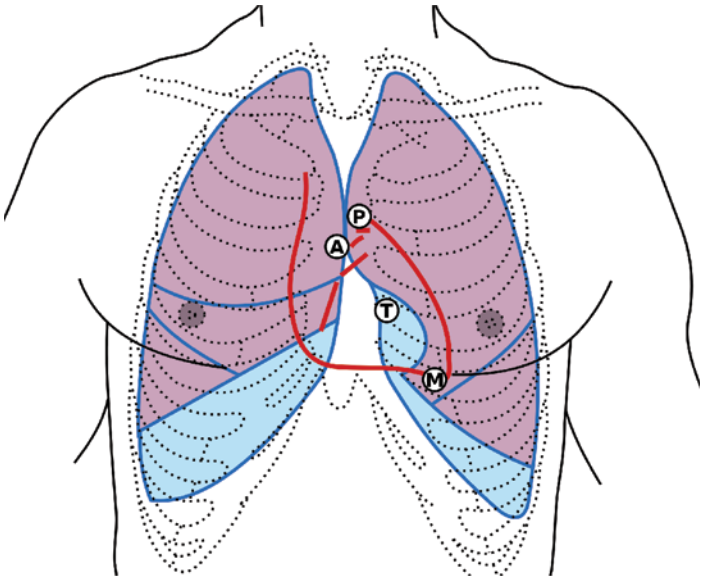
Heart Murmurs

A doctor often listens to the heart from several locations because the heart sounds transmitted to the chest wall can give a clue about the condition of the different valves. Damaged valves can cause different types of **murmurs**. The location, timing, and type of sound help the doctor know what sort of damage is causing it.

If a valve is damaged and allows blood under high pressure to leak backward, a whooshing murmur may be heard. We say such a valve is **incompetent** because it isn't doing the job a valve is designed for — preventing the back-flow of blood. For instance, were the mitral valve to become incompetent, when the left ventricle contracts, some blood would be pushed back through the valve into the left atrium. The turbulence of the blood passing through the damaged valve would produce a murmur.

If a damaged valve is stiff and does not open normally, the outflow of blood is impeded. This is known as **stenosis**. A whooshing murmur will be heard due to the blood struggling to get through. As an example, if the aortic valve were damaged and became stiff or scarred, it might not open as it should. Then when the ventricle contracts, the blood would not as easily pass into the aorta. Again, the turbulence produced by the forcing of blood through the abnormally small opening would result in a murmur.





Optimal stethoscope position for listening to heart valves. Heart valves are labeled (Mitral, Tricuspid, Aortic, Pulmonary).

René-Théophile-Hyacinthe Laennec (1781-1826) invented the stethoscope in 1816. The first stethoscope was a simple hollow wooden cylinder. It allowed doctors to listen to the heart and lungs without having to place their ears directly on the patient. Even though that device is primitive by today's standards, it was revolutionary in its day.

If the first heart sound, the "lub," results from turbulence during the simultaneous closure of the tricuspid and mitral valves, what do you think causes the second sound, the "dub"? The turbulence of blood created when the semilunar valves close creates this second heart sound. If you have the opportunity to borrow a stethoscope, you can listen to your own heart's sound. The heart sounds can both be heard at many locations on the chest wall.

The Cardiac Cycle — What Happens In a Heartbeat

The *cardiac cycle* is the name given to the five steps involved in filling the heart's chambers and pumping the blood. We will now examine this process more closely. All five steps must take place — in just the right order — every time your heart beats.

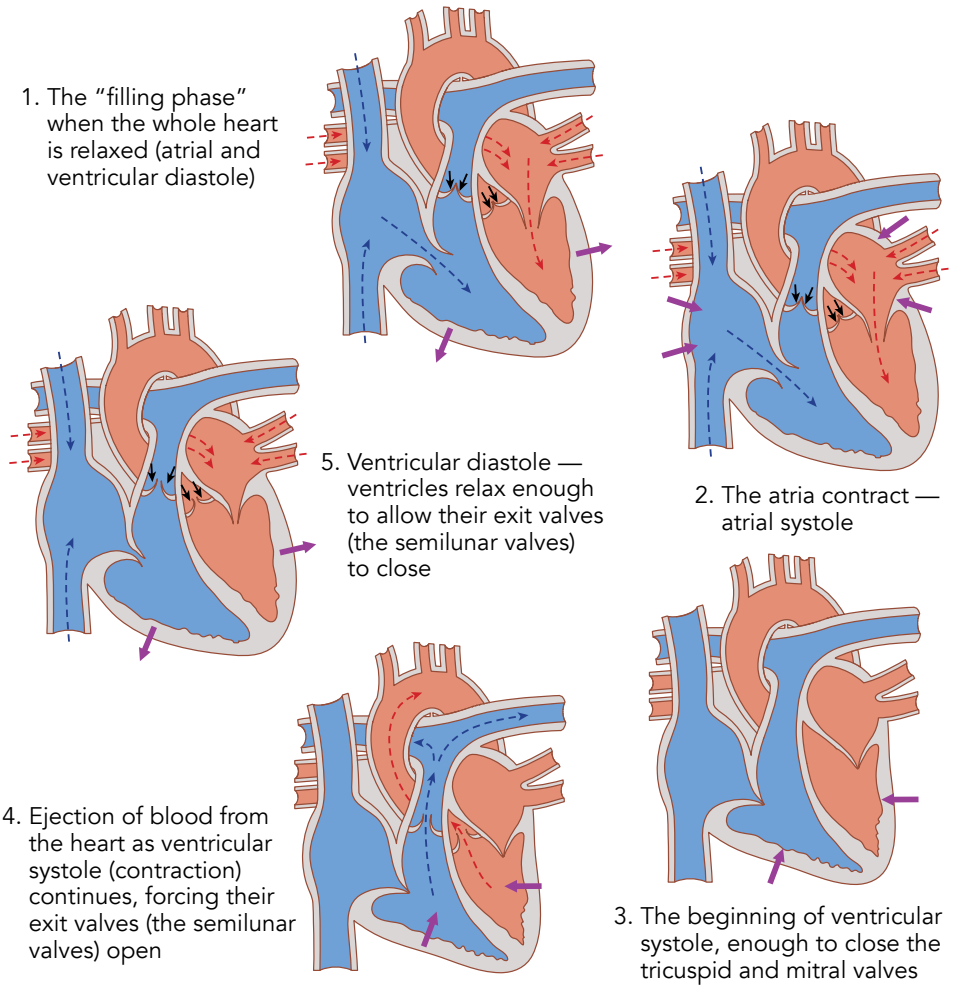
There are specific terms used to describe what a heart chamber is doing during the different steps in the cardiac cycle. The period of time when a heart chamber is contracting is called *systole* (pronounced "sis-tuh-lee"). The phase during which the chamber is relaxing is called *diastole* (pronounced "dī-as-tuh-lee"). Now let's apply those terms — *systole* and *diastole* — to each of the four steps in the cardiac cycle. (Later we will see that these words help us understand a measurement called "blood pressure." You may have even had yours measured!)

The first step in the cardiac cycle is the "filling phase." While they fill with blood, the atria and ventricles are all in diastole. That is, all the chambers are relaxed. Since the heart muscle is relaxed, the pressure inside them is low. This low pressure allows the atria and then the ventricles to fill with blood. First, blood enters the atria. As they fill, blood pushes the tricuspid and mitral valves open, allowing blood to flow into the ventricles too. At the end of this phase, the ventricles are about 75 percent full.

During this phase what do you think is happening with the heart's "exit-doors" — pulmonary and aortic valves? Since the pressure in the ventricles is low at this point, both of these valves will be closed, right? Otherwise, the blood would flow backward into the ventricles. The pressures in the pulmonary artery and the aorta are keeping the pulmonary and aortic valves closed for now.

TAKING A CLOSER LOOK

The Cardiac Cycle



After this passive filling of the ventricles, the atria simultaneously contract. This is *atrial systole*. The squeezing of the atria pushes more blood into the ventricles to help really fill them up. This atrial "squeeze" is the second step in the cardiac cycle, and it adds another 25 percent or so to the filling of the ventricles.

Next comes relaxation of the atria (*atrial diastole* — the second step) and then contraction of the ventricles, or *ventricular systole*. During this, the third step of the cardiac cycle, the ventricles begin to contract. As a result of this contraction the pressure in the ventricles increases enough to slam the tricuspid and mitral valves shut, causing the "lub" sound.

During the fourth step of the cardiac cycle, blood is forcefully ejected from the heart. The increasing pressure from the ventricular contraction forces the pulmonic and aortic valves (the semilunar valves) to open, and the blood rushes out into the pulmonary artery and the aorta.

Finally, in the fifth and final step of the cardiac cycle, the ventricles relax. Because of this relaxation, the pressure in the ventricles decreases. The higher pressure in the pulmonary artery and the aorta causes the semilunar valves to close. Thus, blood is prevented from flowing backward into the ventricles. This is *ventricular diastole*, and it is the end point of one complete cardiac cycle.

So, the five steps in the cardiac cycle are:

1. the "filling phase" when the whole heart is relaxed (atrial and ventricular diastole)
2. the atria contract — atrial systole
3. the beginning of ventricular systole, enough to close the tricuspid and mitral valves
4. ejection of blood from the heart as ventricular systole (contraction) continues, forcing their exit valves (the semilunar valves) open
5. ventricular diastole — ventricles relax enough to allow their exit valves (the semilunar valves) to close

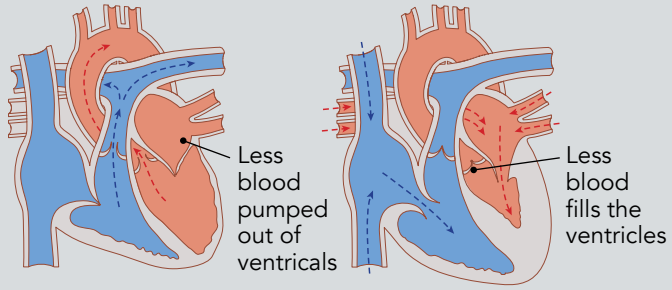
Congestive Heart Failure

The pumping action of the heart is nothing short of amazing. The right side of the heart sends blood to the lungs, and the left side of the heart pumps blood out to the body. Each side pumps the same amount of blood, at the same time, and the process takes place in a coordinated fashion. This precise balance continues day in and day out.

However, we live in a fallen, cursed world. Things go wrong. At times the heart does not function correctly. A heart weakened by disease or heart attack will not be as efficient or pump as powerfully. This is called "heart failure." With heart failure, the heart still works, but one or both of its pumps is weak.

Since the heart consists of two pumps, it is possible for either pump system to function abnormally. If either of the pumps fails to keep up with the amount of blood it is supposed to pump, blood will back up, like cars in a traffic jam. We sometimes say that traffic is "congested," and the same word can be used for blood that backs up due to heart failure. **Congestive heart failure** can be a problem caused by failure of either the right or the left side of the heart to keep up.

If the pump on the right side of the heart fails to pump properly, the blood returning to the heart from the body is not pumped to the lungs efficiently. Then, the vena cavae and other systemic veins that bring blood to them become **congested** with excessive blood. Remember, this is like a traffic jam — traffic congestion — with blood instead of cars. Blood is backed up. Due to this **congestion**, the pressure in these vessels increases. The most noticeable result of this is swelling in the legs and feet. This swelling is called **peripheral edema**. (**Edema** is swelling caused by fluid accumulating in tissues. **Peripheral** means the swelling happens in parts of the body far away from the heart.)



If the pump on the left side of the heart fails to do its job properly, the oxygenated blood returning from the lungs is not adequately pushed out to the body. Now, if the normal amount of blood is being pumped to the lungs by a correctly functioning right heart pump, but the left heart pump cannot keep up with this volume of blood, what do think will happen? The blood will back up into the lungs! This time the "traffic congestion" backs up into the lungs. This problem is called **pulmonary edema** (fluid in the lungs). Pulmonary edema causes patients to be quite short of breath and make it difficult to exercise or even to walk. In its most severe forms, pulmonary edema can lead to death.

The degree of heart failure can be assessed by the severity of the patient's symptoms, such as shortness of breath or how much exercise they can do. Also, it can be quite helpful to obtain a measurement of the patient's ejection fraction — the fraction of the blood ejected during systole. The lower the ejection fraction, the more severe the heart failure is said to be.

Treating heart failure is challenging. Patients are often given drugs that cause the body to get rid of the excess fluid that accumulates in the lungs or other tissues. There are also certain drugs that can help damaged cardiac muscle contract more efficiently and make the heart pump better. However, these drugs can also have serious side effects at higher doses, so they must be used cautiously. In certain very severe cases, a heart transplant may even be considered.

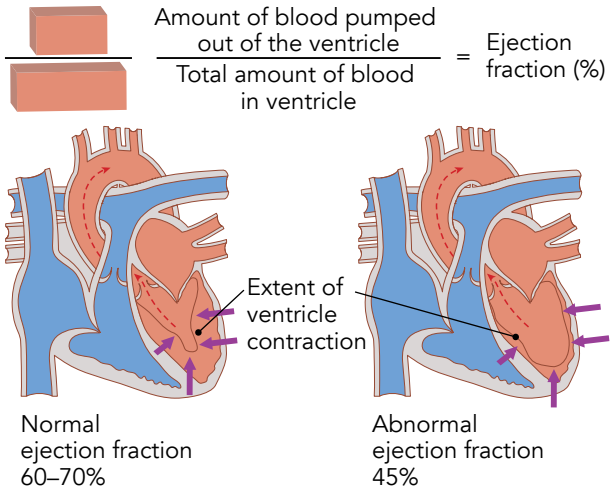
That is what happens every time your heart beats! What do you think happens next? Remember this is a *cycle*, so when the fifth step is completed, the whole cycle begins again. The heart's chambers are all relaxed and the valves are in the right position so that they can fill with blood and the heart can beat again.

How Empty Is Empty?

When you wring out a washcloth or sponge, is it completely dry? No. It still contains some water. You cannot squeeze it enough to make it dry. Likewise, after your heart's ventricles contract, they still contain some blood. Not every drop of blood gets emptied from the ventricles as they squeeze. In fact, a healthy heart only empties around 60–70 percent of its contents with each beat! This percentage is called the *ejection fraction*. If a person's heart is not working properly, its ejection fraction may be far lower than this. Measuring the ejection fraction can be very important for physicians when they are caring for patients with heart problems.

TAKING A CLOSER LOOK

Ejection Fraction



What the Heart Needs

The heart pumps oxygen-rich blood to every organ in the body. But how does the heart get the oxygen-rich blood it needs? After all, the heart needs a constant supply of oxygen and fuel (in the form of sugar called glucose) in order to keep pumping constantly, day in and day out, for a lifetime! Therefore, God designed the *coronary circulation* — a way for the heart to pump blood to itself.

When something goes terribly wrong with the coronary circulation, a person can have a heart attack. You may know of someone this has happened to. Once you see how the coronary circulation works and why it is so important, you will understand what a heart attack is.

You might wonder why the heart needs its own separate blood supply. After all, the heart is a pump that pumps blood. It is filled with blood most of the time. So why can't it just get the things it needs from the blood in its chambers?

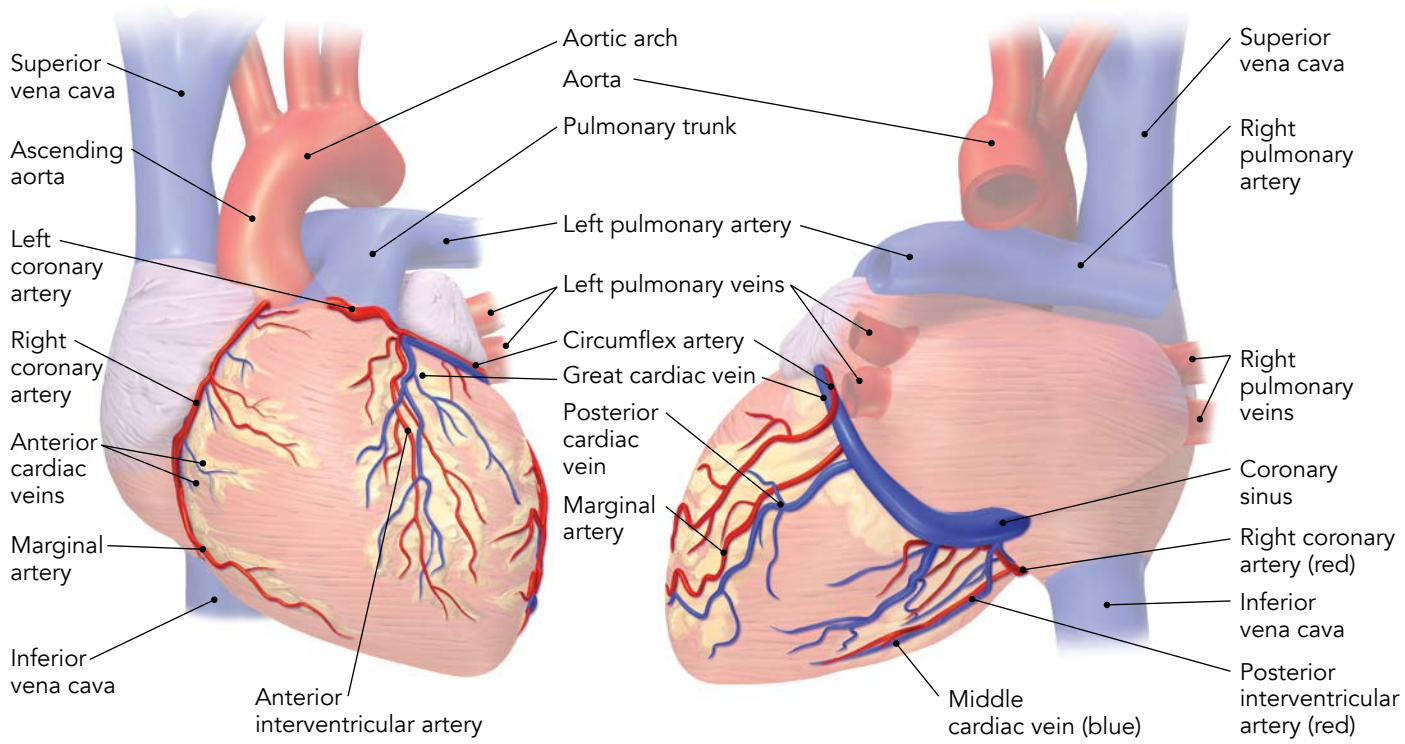
What it comes down to is this: because the heart works constantly, it needs *lots* of oxygen and nutrients. Even though the left ventricle is filled with oxygen-rich blood, the heart wall is just too thick for nutrients to seep into it. A more efficient system is needed to supply the heart muscle — the *myocardium* — with oxygen and fuel.

The *coronary circulation* is a system of arteries and veins that delivers oxygen-rich blood to the heart muscle and carries away deoxygenated blood.

The coronary circulation begins just past the aortic valve. Right after the place where blood exits the heart's left ventricle, two arteries branch from the very first part of the aorta (called the *ascending aorta*). These are the *right and left coronary arteries*. They divert a little of the blood flowing into the aorta toward the heart's muscular walls.

TAKING A CLOSER LOOK

Coronary Circulation



The *right coronary artery* primarily supplies the right atrium and the right ventricle. It divides and divides into many smaller arterial branches to completely supply the right side of the heart.

The *left coronary artery* supplies the left side of the heart. It has two major branches. One of these — the left anterior descending artery, or LAD — supplies the front (*anterior*) walls of both the right and left ventricle as well as the wall of myocardium between the ventricles. (This muscular wall between the ventricles is called the interventricular septum). The other branch — the circumflex artery — brings blood to the left atrium and the left ventricle's back (*posterior*) wall. The two main branches divide and subdivide into many smaller vessels to ensure complete circulation to the left side of the heart.

After supplying the heart's muscular walls with the oxygen and fuel they need, deoxygenated blood returns to the right atrium through several cardiac veins.

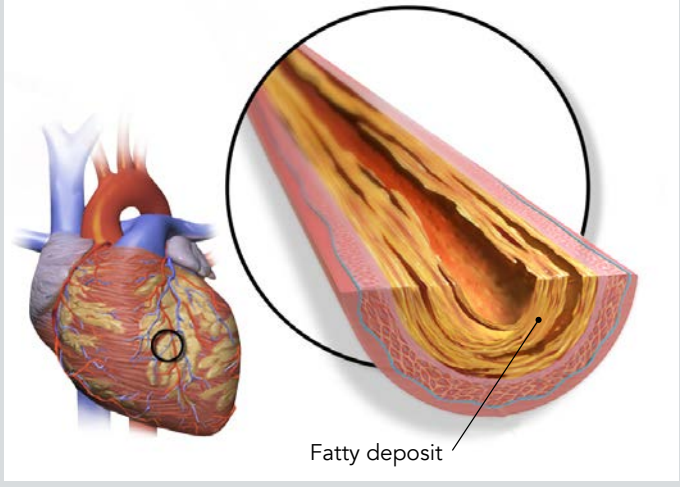
Try This

Squeeze one hand into a tight fist. Then try to push a finger into that fist. You can't! It won't fit if the fist is tightly contracted. Likewise, if your heart is busy squeezing hard — contracting — how can its muscular walls have room to let blood flow through the coronary circulation to bring them the oxygen and fuel they must have to keep working? Well, God is a great engineer. This is the solution He designed: As the heart relaxes during diastole, the pressure in the aorta pushes blood into the coronary arteries to supply the heart. The heart muscle receives most of the oxygen and fuel it needs during the relaxed parts of each heartbeat, enough to keep it going until the next diastole.

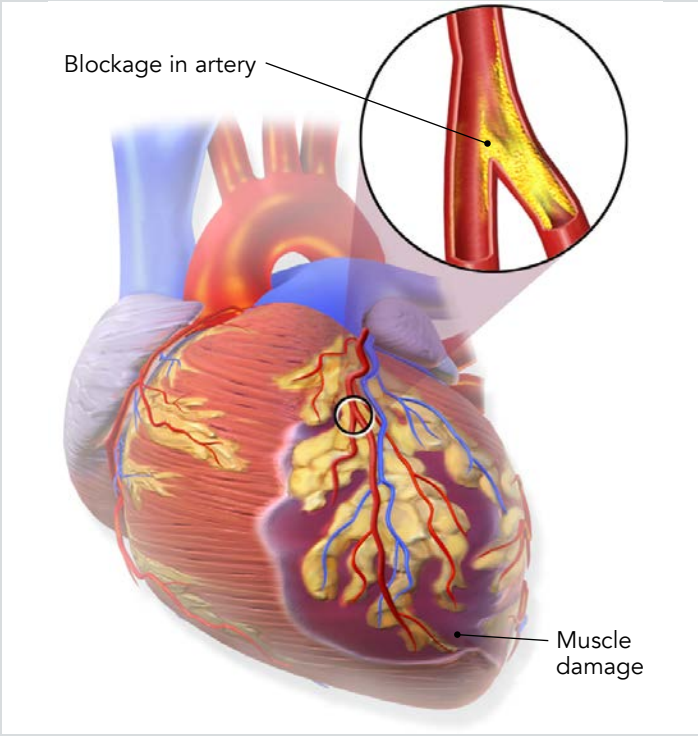
Coronary Artery Disease

It is possible that you know someone who has suffered a heart attack. If not, I expect you have at least heard the term "heart attack." A heart attack can be very serious and is often fatal. Every year over 700,000 people in America have a heart attack!

The primary problem that leads to a heart attack is called **coronary artery disease**. You already know what a coronary artery is. Coronary arteries are the arteries that keep the heart's muscular walls supplied with freshly oxygenated blood. Coronary artery disease, abbreviated CAD, occurs when the lining inside a coronary artery becomes thick. As the lining thickens, the channel inside the artery becomes smaller and smaller. Less and less blood is able to squeeze through the narrowing opening. Severe narrowing is called a "blockage."



Eventually, the blood flowing through this narrowed artery cannot adequately supply the needs of the myocardium. The situation where adequate oxygen is not delivered to the heart muscle is called **myocardial ischemia**. Coronary artery disease can involve a single "blockage" in only one coronary artery or several blockages in multiple coronary arteries. Obviously, the more blocked arteries, the more serious the situation.



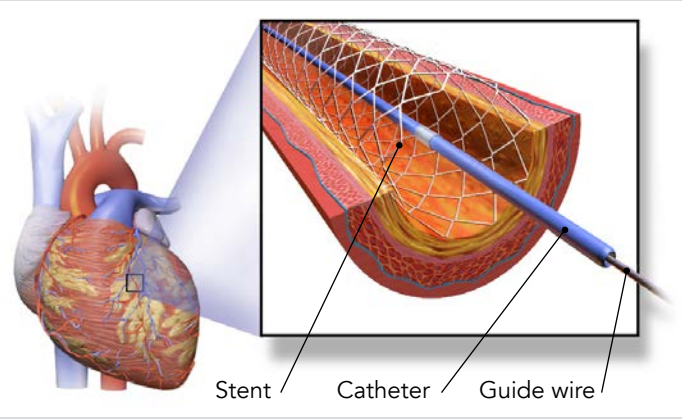
Myocardial ischemia is not the same thing as a heart attack, but it can lead to one. There are degrees of myocardial ischemia. Some people with myocardial ischemia experience episodes of **angina pectoris**, which literally means "strangled chest." A person with angina pectoris has episodes of chest pain, usually described as a tightness or a burning sensation in the chest. Some feel like their chest is in a vise. Often the pain radiates to the left arm, neck, or jaw. Angina pectoris can occur with activity (so-called "stable" angina) or at rest ("unstable" angina). The underlying problem is that due to restriction of blood flow. the heart muscle does not get adequate oxygen to meet its needs, thus resulting in chest pain. However, with angina alone the situation is intermittent, and there is no permanent damage to the heart muscle.

As coronary artery disease worsens, there is increasing danger of myocardial infarction (often called an "MI"). This is commonly known as a heart "attack." Here the disease in the coronary artery (or arteries) has progressed to the point that the myocardium can no longer get the amount of oxygen it needs, and some of the heart muscle dies. Logical, isn't it? If an artery that takes oxygen to a certain

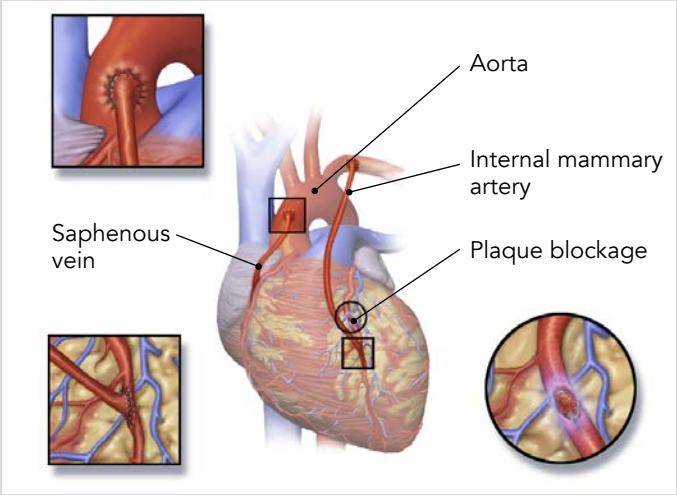
part of the heart becomes blocked, then the muscle tissue in that part of the heart is at risk of death. Myocardial infarctions can range from relatively mild to fatal. The severity depends on how much myocardium is damaged and how efficiently the remaining heart muscle functions.

Treatment for coronary artery disease depends on its severity. If it is very mild, a patient may be treated with simple things like exercise, medication, and changes in diet. For more serious blockages, patients may undergo a procedure to open or to by-pass the blockage in order to improve blood flow to the heart.

There are two main sorts of procedures used to deal with a coronary artery blockage. One is called **coronary angioplasty**. (By the way, the author of this book has undergone this procedure.) Here, using special dye and a type of x-ray called fluoroscopy, a tiny wire is threaded through the blockage and a balloon is inflated to open up the artery. Most often, a small mesh device, called a stent, is then put in place in the coronary artery to help keep it open.



In the most severe cases of coronary artery disease, **coronary artery bypass surgery** is done to route blood around a blockage. In bypass surgery, a section of a vein from the person's arm or leg is removed and used as a bypass graft. One end of the vein is attached to the aorta, and the other end is attached to the diseased coronary artery at a point past the blockage. Thus, the blockage is effectively "bypassed," and blood flow is restored to the heart muscle at risk for damage.



Coronary artery disease is a type of **cardiovascular disease**, a term that includes heart attacks and strokes and other diseases of the heart and blood vessels. Cardiovascular disease is the world's leading cause of death. Heart attacks are the leading cause of death in the United States.

Who is most likely to have a heart attack? Some people are at greater risk than others. A **risk factor** is something that puts a person at greater risk of suffering a particular thing than other people. Some risk factors are beyond a person's control. However, there are some things you can do to lower the risk of ever having a heart attack. There are many risk factors that can lead to heart disease. These include (but are not limited to) smoking, a lack of exercise, obesity, poor diet (especially diets high in fats), high cholesterol, diabetes, and high blood pressure.

We need to take all the steps we can to take good care of our hearts. So make a lifelong practice of getting plenty of exercise (and, no, video games are not exercise), maintain a healthy weight, get in the habit of primarily eating nutritious foods (I'm not saying don't eat hot fudge sundaes, I'm just saying don't make a regular habit of them), and never, ever . . . let me say it again . . . never, EVER, start smoking!

Now is the time to learn a heart healthy lifestyle!

Beats

As we mentioned earlier, cardiac muscle is involuntary. This means you don't have to think about your heart beating. It happens all on its own. Unlike skeletal muscle, you have no conscious control over the contraction of cardiac muscle. For example, you can willfully make skeletal muscle move . . . reaching for a glass or throwing a ball. However, you cannot will your heart to beat.

It turns out that just beating isn't enough. Not only must the heart beat (and even be able to speed up when you are running), but both sides must beat simultaneously. Remember, the heart is really two pumps. How does it get the timing right so that both sides pump simultaneously? The answer is electrical. Your heart has a built-in system to produce an electrical signal that triggers the heart muscle in each pump to beat . . . and to do it over and over and over again.

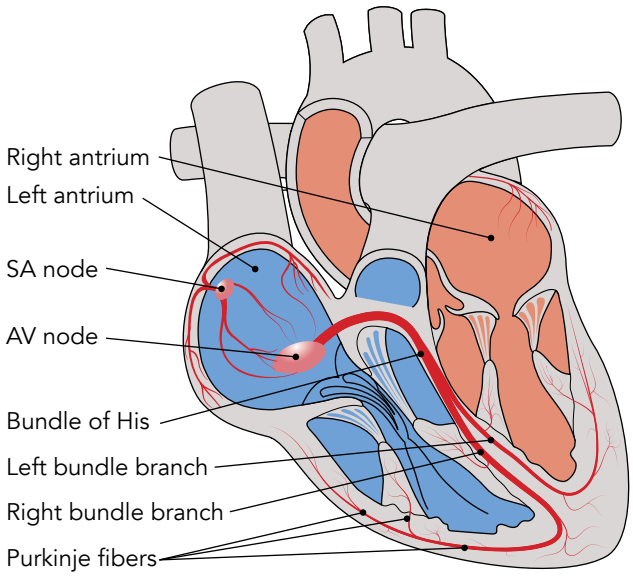
The Pumping Heart

Most of the heart consists of cardiac muscle cells. The vast majority of these muscle cells are in the business of contracting. They are responsible for the pumping action of the heart. However, about 1 percent of these cells have a very special property and are not primarily involved in heart contraction. These special cells are the ones that *stimulate* the contractions! These cells have the ability to spontaneously generate an electrical signal all on their own. These are called *autorhythmic* ("self-rhythm") cells. They repeatedly produce electrical signals that stimulate the heart to contract.

These autorhythmic cells generate electrical impulses without any outside stimulus from the nervous system. Even if all nerve fibers to the heart were severed, the heart would continue to beat. For example, hearts removed from a body to be transplanted continue to beat for several hours, even though all nerve fibers to the heart have been cut. (This does not mean that the nervous system is not important. Nervous system input can play an important role in controlling the heart *rate* as we will see.)

TAKING A CLOSER LOOK

Cardiac Conduction System



These autorhythmic cells have two important jobs. First, they function as the *pacemaker* for the heart. That is, they establish and maintain the basic rhythm of the heart. They trigger the start of each and every heartbeat. They set the pace! Second, they are lined up to form a pathway that helps move the electric signals through the heart from muscle cell to muscle cell in a very orderly fashion.

The cardiac conduction system is also called the *intrinsic conduction system*. *Intrinsic* means this conduction system is completely contained within the heart; it does not bring in messages from outside the heart. This intricate network of rhythm-generating cells is designed to distribute signals to the cardiac muscle in an orderly way to ensure that the heart contracts in a coordinated manner. If the heart's chambers did not coordinate their

squeezing action, chambers would start squeezing before they filled. Furthermore, just as a toothpaste tube squeezed near the top traps toothpaste in the bottom of the tube, so a heart that doesn't squeeze in a coordinated manner would not empty blood very well. Let's take a closer look at the way the electrical system of the heart is designed to avoid this sort of problem.

The Cardiac Conduction System

The cardiac conduction system (or intrinsic conduction system) has two "nodes" that set the pace of the heartbeat. The first node to fire signals the beginning of a heartbeat. This pacesetter is the *sinoatrial node*, also called the *SA node*. The SA node is a small group of cells located in the upper portion of the right atrium's wall, near the entrance of the superior vena cava. The SA node is the heart's main pacemaker. The SA node initiates each electrical *impulse* that stimulates the heart to contract. On average, the SA node generates an impulse 72 times a minute. The SA node generates impulses faster than the other pacemaking node. Therefore, under normal circumstances, the SA node controls the heart rate. For that reason, the basic rhythm of the heart is called *sinus rhythm*.

Once generated, the impulse from the SA node travels through the muscle cells themselves. The impulse spreads throughout both atria causing them to contract. Atrial contraction squeezes the blood from each atrium into the ventricles.

At the end of its journey through the atria, the electrical impulse produced by the SA node reaches another group of cells called the *atrioventricular node* (AV node). The AV node is located in the wall (or *septum*) between the right and left atria, just above the tricuspid valve. It is the job of the AV node to send the electrical signal on to the ventricles. That signal makes the ventricles contract. (If, however, the SA node fails for some reason, the AV node can act as a backup system and stimulate the heart to beat.)

Do you see a problem here?

These electrical impulses travel very rapidly. What would happen if the atria and the ventricles all contracted at the same time? The atria would not be able to squeeze their blood into the ventricles because the ventricles would be contracting too. And without getting re-filled with blood from the atria, the ventricles would soon have no more blood to pump out to the body and the lungs. The entire heart would stop pumping blood. Not a good situation at all, right? The beating of the heart must be coordinated, so that the atria both contract before the ventricles do.

God has designed the cardiac conduction system to avoid this problem. When the SA node "fires," both

How Fast?

As we examined the cardiac conduction system, we saw that the SA node is the primary pacemaker of the heart. The SA node beats at an average rate of 72 beats a minute.

Are there other pacemaker locations in the heart? As it turns out, there are.

If the SA node ceased to function (say, as a consequence of disease or aging), the AV node would take over the pacemaker duties. However, the heart rate generated by the AV node is around 50 beats per minute.

And if both the SA and AV nodes stopped working, the Purkinje fibers also have the potential to act as a pacemaker. Purkinje fibers can only generate a heart rate of around 30 beats as minute. This is certainly not ideal, nor is it as efficient as a properly functioning SA node.

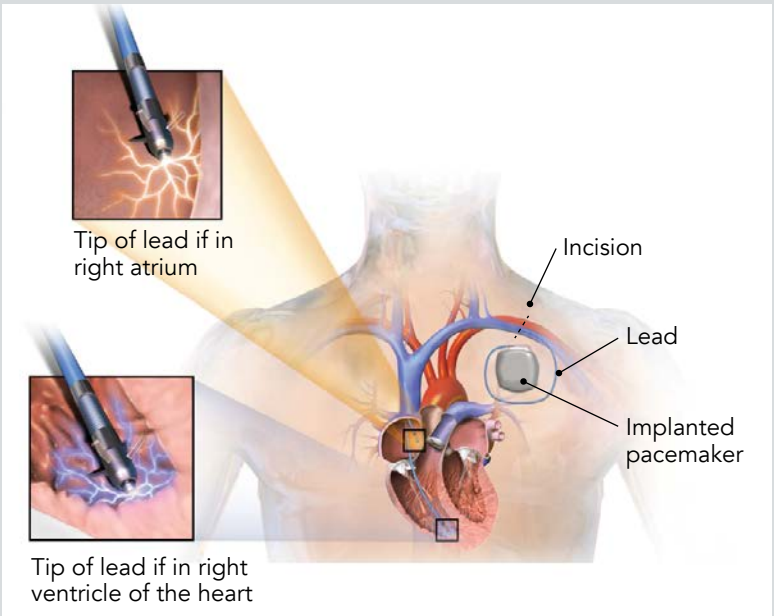
God designed two backup systems to keep the heart beating if its chief pacemaker malfunctions.

atria respond almost instantly, and then the AV node "fires." But when the AV node fires, the ventricles do *not* respond immediately. Instead, the AV node's electrical signal is delayed by about 0.1second (that's one-tenth of a second . . . not very long at all . . . but long enough). This delay happens because the cells in the fibers near the AV node do not transmit the electrical impulse as rapidly. (They have fewer *gap junctions*, little gateways between cells, and that slows down the passage of the impulse from cell to cell.) Once through the AV node and these signal-slowing muscle fibers, the signal travels normally (that is, very rapidly) through the remainder of the conduction system.

After leaving the AV node, the signal is carried by the *atrioventricular bundle* (sometimes called the *bundle of His*) into the ventricles. You might be thinking, "Wait a minute, we just saw that this impulse was carried through the atria though the muscle cells themselves. Why can't the signal that passed through the atria reach the ventricles the same way?" Good question. The answer is that the atria and ventricles are separated by the connective tissue that makes up the fibrous skeleton of the heart. This fibrous tissue acts as sort of an insulator that stops the electrical signal from passing directly. The only electrical pathway between the atria and the ventricles is the atrioventricular bundle. Here is

Pacemakers

Even though a healthy heart does have the ability to generate its own conduction signals, there are circumstances when the cardiac conduction system does not function correctly. At times due to aging or illness, the pacemaker center (SA node) may not generate signals rapidly enough to maintain adequate blood pressure. Or perhaps as the consequence of a heart attack, the AV node is damaged and cannot conduct the electrical signals to the ventricles properly.



In many situations like these a patient may require the implantation of a pacemaker. A pacemaker is a small battery-powered device that can help control a patient's heartbeat. The device is attached to a small electrode that is placed in the heart. An electrical signal is sent from the pacemaker to stimulate the heart to beat.

The simplest style of pacemaker has one electrode that is threaded into the right ventricle (under fluoroscopic guidance). The pacemaker itself is usually placed in a small surgically created pocket under the skin just below the left collarbone. The pacemaker can monitor the patient's heartbeat, and if a beat is not detected within a certain period of time, the pacemaker sends an electrical impulse to stimulate the heart. If a normal heartbeat is detected, then the pacemaker would not fire.

Pacemakers have become more and more sophisticated. These devices can be programmed for a wide range of heart rates. Some pacemakers have multiple electrodes and can pace both the atrium and the ventricle. Other pacemakers sense activity levels and can adjust the patient's heart rate to match.

but one more example of the marvelous design of the heart. Without this electrical barrier it would not be possible to control the pumping action of the heart so precisely.

Very soon after reaching the ventricles, the atrioventricular bundle splits into two branches, the *right bundle branch* and the *left bundle branch*. These two bundles proceed down through the *interventricular septum* (the wall between the ventricles) toward the apex of the heart. The right bundle branch delivers the impulse to the right ventricle and the left bundle branch signals the left ventricle. In the septum, the bundle branches also to small branches that penetrate deep into the myocardium of the ventricles. These are called Purkinje fibers. Because the *Purkinje fibers* deliver the electrical signals to their final destination, they are vital for maintaining the heart's smooth, coordinated pumping action. Purkinje fibers cause the heart to contract from the bottom up and not from the top down.

Heart Squeeze

When the AV node's signal is transmitted, the heart muscle cells in the ventricles do not contract at the same time. What would happen if they did? The blood in the ventricles would get a hard squeeze, but it wouldn't move efficiently toward the aorta and pulmonary artery. To avoid this problem, God has designed the heart's conduction system to start responding to the signal from the apex (the sort of pointy part at the bottom of the heart) and move toward the top of the ventricles. The heart's muscle cells are arranged in a spiral so that they contract and efficiently push the blood in the ventricles out, squeezing from the apex upward. So the heart really does squeeze from the bottom up, and that's the most efficient way!

Think of squeezing a tube of toothpaste. Is it better to squeeze it from the top or the bottom?

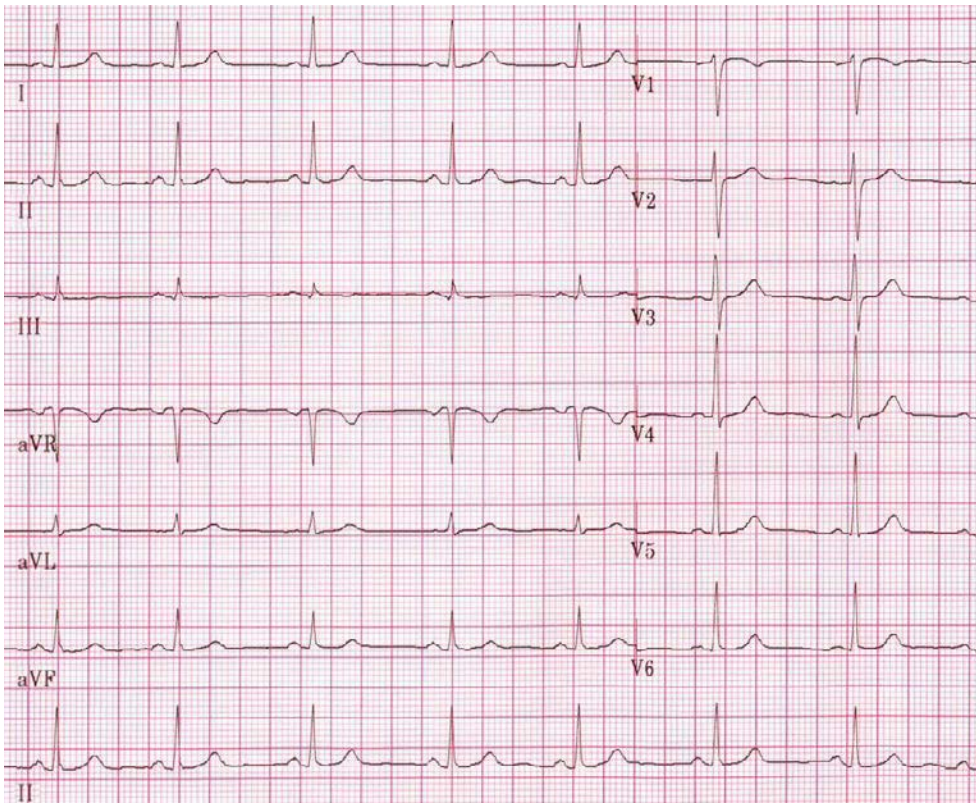
Remember, the heart's conduction system is designed (1) to set its own pace by generating an electrical impulse and (2) to send that signal to all parts of the heart in a coordinated manner that first triggers the atria to squeeze blood into the ventricles and then causes the ventricles to squeeze that blood out from the bottom to the top. See if you can name the parts of the conduction system in the order an impulse travels through them.

The Electrocardiogram

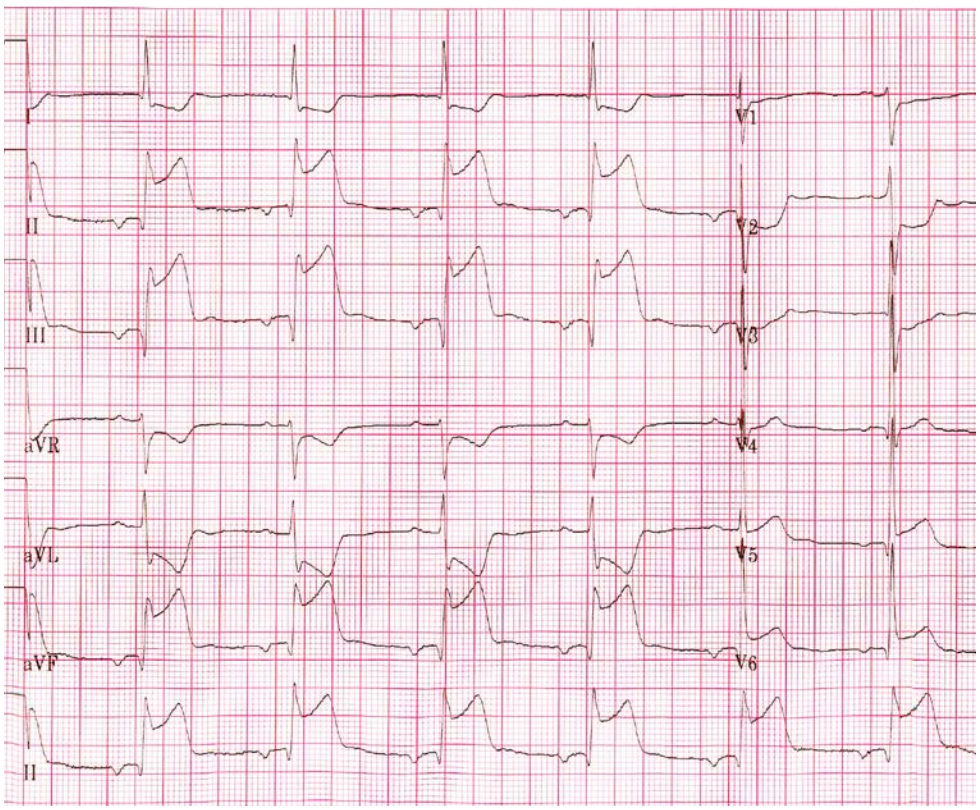
The electrical impulses transmitted through the heart can be detected on the body's surface. The heart's electrical signals can be measured with an electrocardiograph. The recording that is produced from this is called an *electrocardiogram* (abbreviated ECG or EKG).

To record an ECG, one electrode (called a *limb lead*) is placed on each arm and leg. (This does not hurt.) Then six other electrodes are placed across the front of the chest. These are the *chest leads*. Multiple

Getting an Electrocardiogram



Normal 12 lead Electrocardiogram



12 lead electrocardiogram of patient having a heart attack. Note the distinct differences from the normal EKG above.

leads are necessary in order to measure the electrical signals from many different positions relative to the heart. The electrocardiograph machine amplifies the signals obtained by the various electrodes and prints out the patterns as an electrocardiogram.

The ECG tracing is a reflection of the electrical signal being transmitted through the cardiac conduction system. As your eyes move from left to right along the tracing, you are seeing a measurement of the electrical signal as it signals each part of the heart in turn. The ECG shows us the electrical signal that instructs the heart to beat and reveals how well that signal travels through the heart, but it does not actually show the heart's response to that signal — the squeezing of the muscle. Other techniques, such as the *echocardiogram*, show the actual beating of the heart.

The first major wave seen on the ECG is called the *P wave*. The P wave reflects the electrical signal that begins the domino effect that ultimately makes the heart beat one time. The P wave reflects the movement of the electrical impulse from the SA node through the myocardium of the atria. About 0.1 second after the P wave begins, the atria contract. The flat segment between the P

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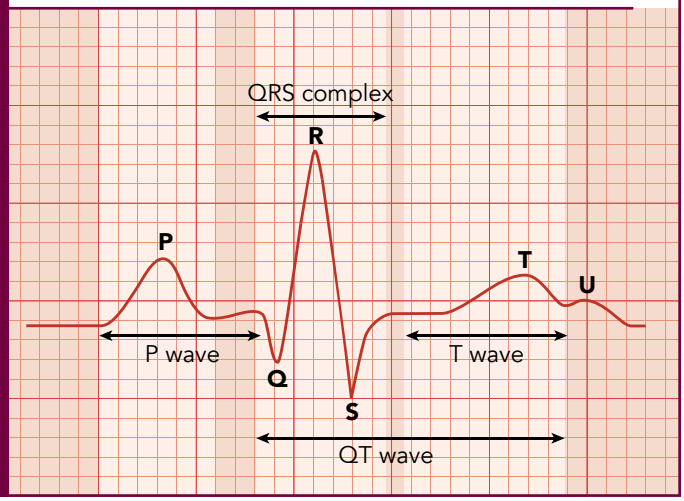
Electrocardiogram



wave and the beginning of the QRS represents the time after the signal has passed through the atria and is being delayed in the AV node. Remember, it is this delay at the AV node that gives the atria time to squeeze their blood into the ventricles before they contract.

The second large wave seen in a typical ECG is called the *QRS complex*. During the time reflected in the QRS complex the electrical impulse is moving through the ventricles. The QRS complex has a complicated appearance due to the paths that the electrical impulses travel as they move through the ventricular myocardium. This is the time when the ventricles contract. The QRS lasts about 0.1 second.

The last wave in an ECG is the *T wave*. During this time, the ventricle is starting to relax. The ventricles are preparing to receive the next electrical impulse. The duration of the T wave is about 0.16 second, and during this time the electrical system of the heart resets itself in preparation for the next heartbeat.

Then the process begins again.

By understanding the pattern and timing of normal ECGs, doctors can use abnormal ECG patterns to help diagnose and treat patients. In fact, ECGs have become one of the most important tools in modern medicine. Damaged cardiac muscle, for instance, might not transmit the electrical signal properly, and this can be revealed in the ECG. ECGs can be particularly helpful in diagnosing coronary artery disease and cardiac rhythm disorders.

Cardiac Output

To more completely understand how the heart works, there is another concept you must understand. This is known as cardiac output.

Cardiac output (CO) is the amount of blood pumped by the heart in one minute. Cardiac output can vary from minute to minute. For example, when you are running, your leg muscles need more oxygen, right? Of course they do. So what do you think happens to the output of the heart when these muscles need more oxygen? It increases!

When you are asleep, your leg muscles need less oxygen, right? So what happens to the heart output when less oxygen is needed? It is not as high.

Cardiac output is the product of two things: the heart rate (HR) and the stroke volume (SV). *Heart rate* means just what it says, the rate of the heart in beats per minute. *Stroke volume* is the amount (volume) of blood pumped with each heartbeat.

The relationship can be shown this way:

$$CO = HR \times SV$$

So let's calculate an average cardiac output. If the average heart rate is 72 beats per minute, and the stroke volume is 70mL, then

$$CO = 72 \text{ beats/minute} \times 70\text{mL/beat}$$

$$CO = 5040\text{mL/minute}$$

$$CO = 5.04 \text{ liters/minute}$$

$$(CO = 1.33 \text{ gallons/minute})$$

This is a typical cardiac output for an adult at rest.

There are two ways that the cardiac output increases — either the heart rate increases or the stroke volume increases. As you are aware, with exercise, the heart rate increases. You've probably felt your heart beating very fast at the end of a sprint. What you may not realize is that with exercise, your heart's stroke volume — the amount of blood pumped out with each beat — can also increase. If, while running, your heart rate goes to 110 beats per minute and the stroke volume increases to 100 mL (3.4 ounces) per minute, what is the cardiac output?

CO = 110 beats/minute x 100 mL/beat

CO = 11,000mL/minute

CO = 11 liters/minute

(CO = 2.9 gallons/minute)

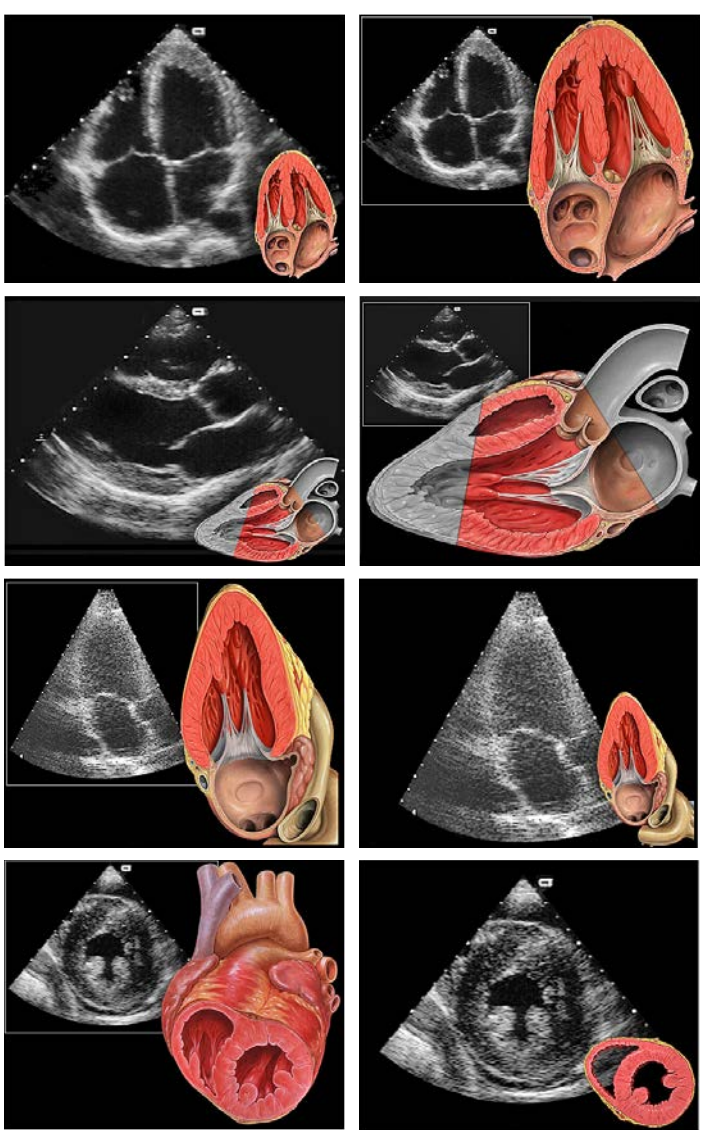
So we see that with only mild increases in heart rate and stroke volume, the cardiac output more than doubles! Soon we'll see how the body can let the heart know that it must pump out more blood — that is, that it must increase its cardiac output.

Echocardiogram

An echocardiogram is an ultrasound of the heart. Whereas the EKG evaluates the heart's function by measuring electrical conduction, an echocardiogram uses sound waves to see inside the heart. Using a *transducer* placed on the patient's chest, sound waves are painlessly bounced off various parts of the heart. The resulting pictures show the heart's shape, its walls, valves, and even the blood flowing through its chambers.

By using sound waves to see inside the heart and make measurements, doctors can determine if the heart is working normally or not. Do the walls move properly? Are they too thick? Is the heart enlarged? Do the valves close completely, or does blood leak back through them? How much blood do the heart's chambers pump out with each squeeze? The heart's ejection fraction, a valuable way to assess how well it is pumping, can be calculated based on information from the echocardiogram.

Here you can see samples of echocardiographic images.



Cardiac Reserve

Some people's hearts are able to increase their cardiac output more than others. A healthy person who runs regularly, for instance, may be able to increase his or her cardiac output much more than a person with heart disease can. We say their *cardiac reserve* is greater.

Cardiac reserve is the difference between the cardiac output at rest and cardiac output during maximal exertion. The average person's heart can increase its output about five times above its resting output. That would be around 24 liters/minute (6.5 gallons/minute). In a highly trained athlete, the maximum cardiac output during heavy exertion might reach 33 liters/minute (9 gallons/minute), or seven times the resting CO.

Regulation of Stroke Volume

Increasing cardiac output requires an increased heart rate, or increased stroke volume, or both. Let's look at ways the stroke volume can increase.

Stroke volume, remember, is how much blood the heart pumps out during one heartbeat. The heart, no matter how healthy, does not empty itself completely during a beat. There is always some blood left behind. Therefore, stroke volume is the difference between the amount of blood in the left ventricle when it is completely relaxed and the amount of blood remaining in the left ventricle when it has just finished contracting.

The ventricle's time of relaxation and filling is called *diastole*, you recall, so the amount of blood in the ventricle when it is full is known as the *end diastolic volume*. *Systole* is the time of contraction, so the amount of blood left in the ventricle after it contracts is called the *end systolic volume*. We could sum this up like this:

End diastolic volume – End systolic volume = Stroke volume

We've said that the heart can increase its stroke volume in order to supply the body's increased needs, like when you want to run. There are several factors that affect stroke volume, but the two most important are *preload* and *contractility*. Preload depends on how much blood is in the left ventricle before it squeezes. Contractility involves how hard the ventricle squeezes. Let's look at these two things more closely.

Cardiac muscle cells contract most efficiently when they are stretched somewhat before they begin contracting. *Preload* is the amount that cardiac muscle is stretched by the blood in the ventricle before it contracts. The more blood that enters the ventricle, the more its walls are stretched. This stretching helps increase the force of the contraction of the muscle. Imagine blowing up a balloon. The more air you blow into a balloon, the more the balloon stretches. Up to a point, the more the ventricle is stretched (preloaded), the stronger will be its contraction.

Preload depends on the amount of blood that can enter the ventricle before it beats. Let's consider how preload can change. The heart's *rate* can alter its preload. If it beats slowly, there is more time between

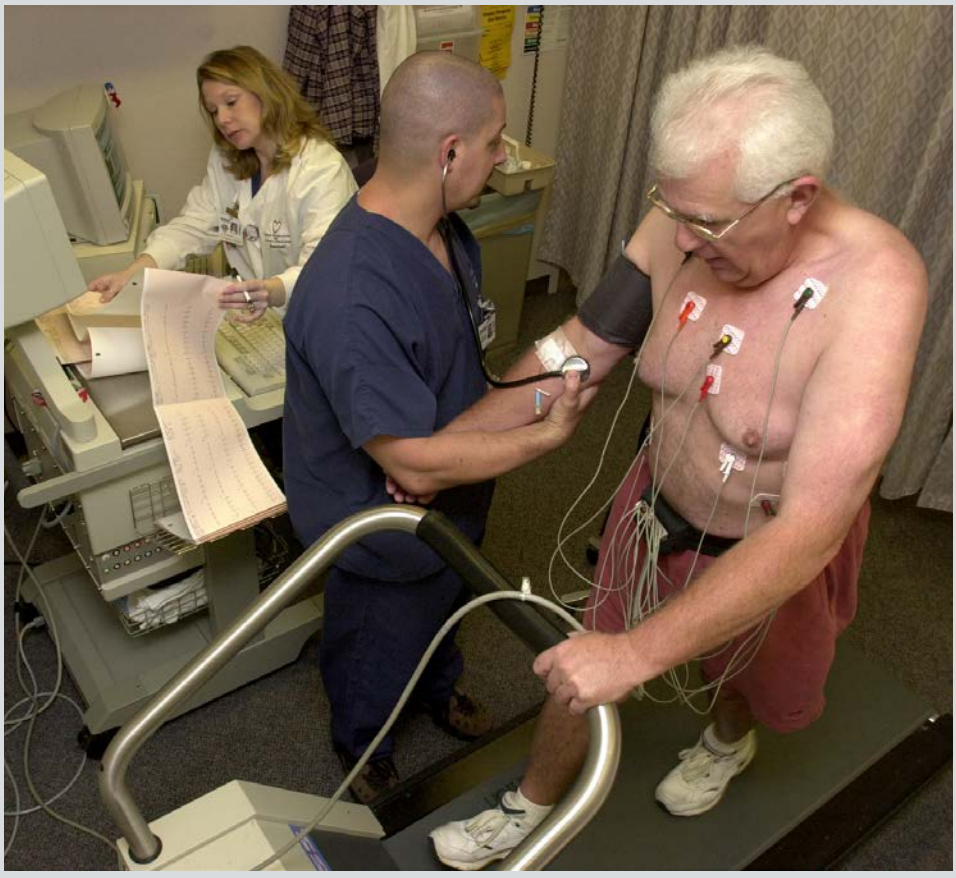
beats. This allows more time for blood to fill the ventricles and increases stroke volume. The opposite can occur with extremely fast heart rates. A very rapidly beating heart leaves little time between beats to fill the ventricle, and the stroke volume could consequently decrease.

The heart muscle's contractility also helps determine stroke volume. *Contractility* refers to how hard the muscle can contract when it is stretched to a certain point. When you are running, your body can send messages to the heart to increase contractility. Some of the most important chemical messengers in the body are called hormones. *Hormones* travel through the blood stream to deliver their messages to many destinations in the body. The hormones *epinephrine* and *norepinephrine* (also called *adrenaline* and *noradrenaline*) can increase the contractility of cardiac muscle, making the muscle squeeze more forcefully. When the heart squeezes harder, it empties more completely with each beat. Thus, stroke volume increases.

Stress Testing

A heart suffering from coronary artery disease might have sufficient blood circulation to function normally at rest but not when stressed with exercise. Therefore, one of the most common tests performed to detect coronary artery disease is called an exercise test, or a "stress" test.

An exercise stress test is performed by having the patient walk on a treadmill while connected to an EKG monitor. Every few minutes, the speed and incline of the treadmill are increased, thus demanding more work from the patient's heart. (Those patients unable to walk on a treadmill can be tested using vigorous arm exercises or an exercise bicycle.) The test ends when the patient cannot continue or when a specified heart rate is achieved.



During the stress test certain characteristic EKG patterns may suggest the presence of coronary artery disease. Abnormal heart rhythms also commonly develop during the exertion of the stress test. These rhythms are recorded on the EKG tracings for evaluation.

Although primarily thought of as a test to detect disease, stress tests are also useful in other ways. For example, special types of stress tests are sometimes used to evaluate and monitor the conditioning of healthy athletes as a part of their training regimen.

Regulation of Heart Rate

We said the increased cardiac output requires an increased heart rate, or increased stroke volume, or both. Just as there are factors that regulate stroke volume, there are factors that regulate heart rate. The SA node is the heart's main pacemaker. The SA node is part of the heart's *intrinsic* conduction system — a signaling network *inside* the heart — but it responds to input from the nervous system, hormones, and other stimuli.

Everyone knows that our heart beats faster when we are frightened or excited. This increase in heart rate is due in large part to stimulation of the cardiac conduction system by the nervous system. Nerve fibers from the *sympathetic nervous system* release a chemical (norepinephrine) that binds to special receptors on the heart. Sympathetic nerve stimulation causes the SA node to fire more rapidly, and thus increases the heart rate.

The nervous system can also cause the heart rate to decrease. The *parasympathetic nervous system* has effects opposite to the sympathetic nervous system. (We will learn much more about these two divisions of the nervous system in other volumes of *Wonders of the Human Body*.) Parasympathetic fibers release a different chemical (acetylcholine) to slow the speed at which the SA node fires.

The primary pacemaker of the heart, the SA node, fires at an average of 72 beats per minute. However, the SA node is actually "pre-set" at a rate of nearly 100 beats per minute. The SA node fires at a slower average rate because it is reined in the parasympathetic nervous system's input.

Heart rate can be influenced by other things, such as hormones — chemical messengers that travel though the blood stream. One of these — adrenaline (also called epinephrine) — is made by the adrenal glands when you are exercising and when you are frightened. Adrenaline (epinephrine) increases heart rate. Thyroxine, a hormone produced by the thyroid gland, can also increase the heart rate. Fever can increase the heart rate, and an abnormally low body temperature can lower the heart rate.

UNIT 3

THE NERVOUS SYSTEM

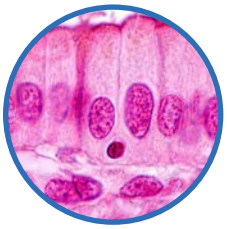
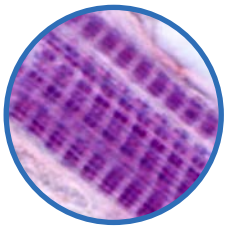
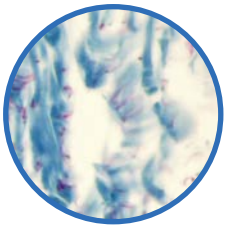
wonders of the HUMAN BODY

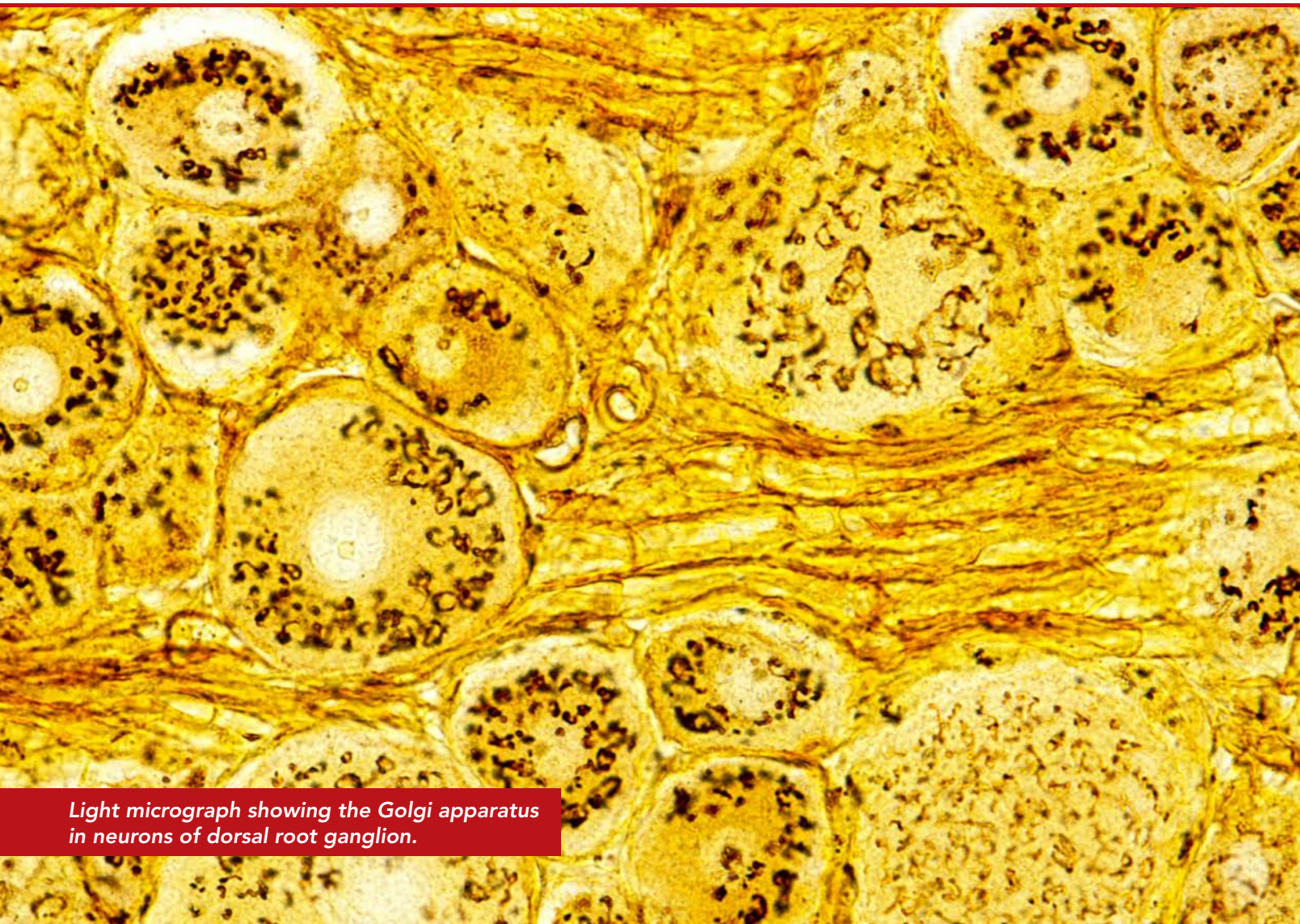
2

STRUCTURE OF NERVOUS TISSUE

The nervous system is composed primarily of nervous tissue. Nervous tissue is one of the four basic tissue types that we examined previously in Volume 1 of *Wonders of the Human Body*.

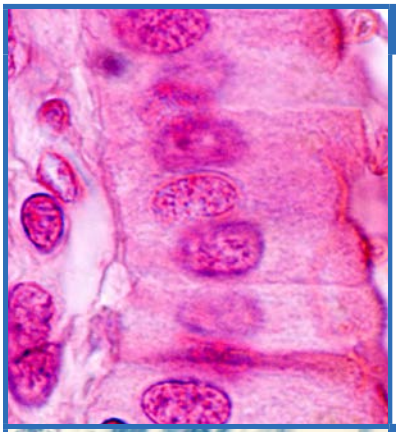
Nervous tissue consists of two primary types of cells: neurons and neuroglia.

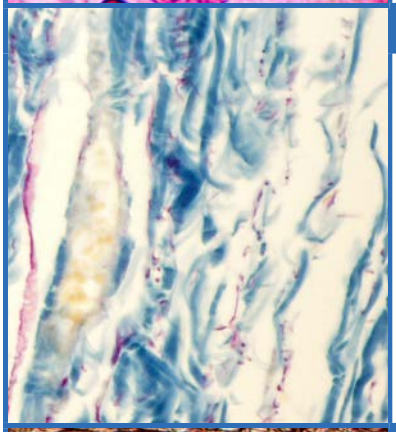
Light micrograph showing the Golgi apparatus in neurons of dorsal root ganglion.

Tissue Types



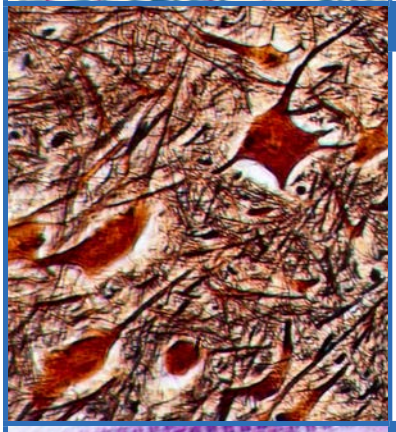
Epithelial Tissue

Epithelial tissue (or epithelium) lines body cavities or covers surfaces. For example, the outer layer of skin is epithelium. The sheet of cells that line the stomach and intestines, as well as the cells that line the heart, blood vessels, and the lungs, is epithelial tissue.



Connective Tissue

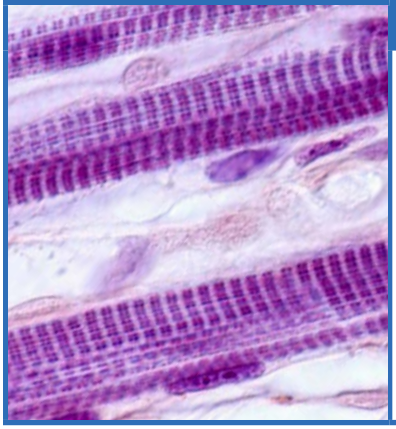
Connective tissue helps provide a framework for the body. It also helps connect and support other organs in the body. Further, it helps insulate the body, and it even helps transport substances throughout the body. This tissue can be hard or soft. Some connective tissue stretches. One type is even fluid. Connective tissue is comprised of three parts: cells, fibers, and ground substance.



Nervous Tissue

Nervous tissue is the primary component of the nervous system. The nervous system regulates and controls bodily functions.

Nerve cells are incredible. They are able to receive signals or input from other cells, generate a nerve impulse, and transmit a signal to other nerve cells or organs.



Muscle Tissue

Muscle tissue is responsible for movement. There are three types of muscle tissue: skeletal muscle, smooth muscle, and cardiac muscle.

Neurons are the excitable nerve cells that transmit electrical signals.

What starts such an electrical signal? Some type of change in the environment acts as the stimulus that excites a neuron, triggering an electrical signal called an action potential. The electrical signal transmitted by a neuron is also called an impulse. An impulse travels like a wave along the nerve cell membrane from one end of the neuron to another. We will soon study this in depth.

The other cells in nervous tissue are called neuroglia. There are several types of neuroglia cells. They help protect and support the neurons.

Let's examine the neuron in greater detail.

Neurons

The neuron is often called a nerve cell because it is the cell type that does the primary work of the nervous system. You have neurons in your brain, in your spinal cord, in your peripheral nervous system, and even in specialized sensory organs like your eye, nose, and ear.

A neuron doesn't look like a typical cell. If you have seen sketches of "typical" cells before, you will notice that, while the neuron still has a cell membrane, cytoplasm, and a nucleus, it has an unusual shape. The neuron is a very specialized type of cell that is designed to transmit electrical impulses (nerve impulses) rapidly to various parts of the body.

The neuron is composed of three parts: the cell body, dendrites, and the axon.

The cell body contains the typical organelles we discussed at length in Volume 1 of *Wonders of the Human Body*. The cell body contains a nucleus surrounded by cytoplasm. The cytoplasm contains plenty of protein-building organelles like rough endoplasmic reticulum dotted with ribosomes and free ribosomes. An extensive Golgi apparatus processes the proteins made by these ribosomes. Neurons require a lot of energy to build the substances they require, so lots of energy-generating mitochondria are also found in the cell body. Energy provided by these mitochondria fuels the building of the substances neurons need to do their job. Some of the most important substances synthesized in the neuron's cell body are neurotransmitters. As we will soon see, neurotransmitters are the chemicals that transmit an electrical impulse from one neuron to the next.

Extending from the cell body are numerous projections, or processes. Neuron cell bodies have two kinds of processes protruding from them, dendrites and axons. Dendrites are designed to receive signals. Axons are designed to carry signals away.

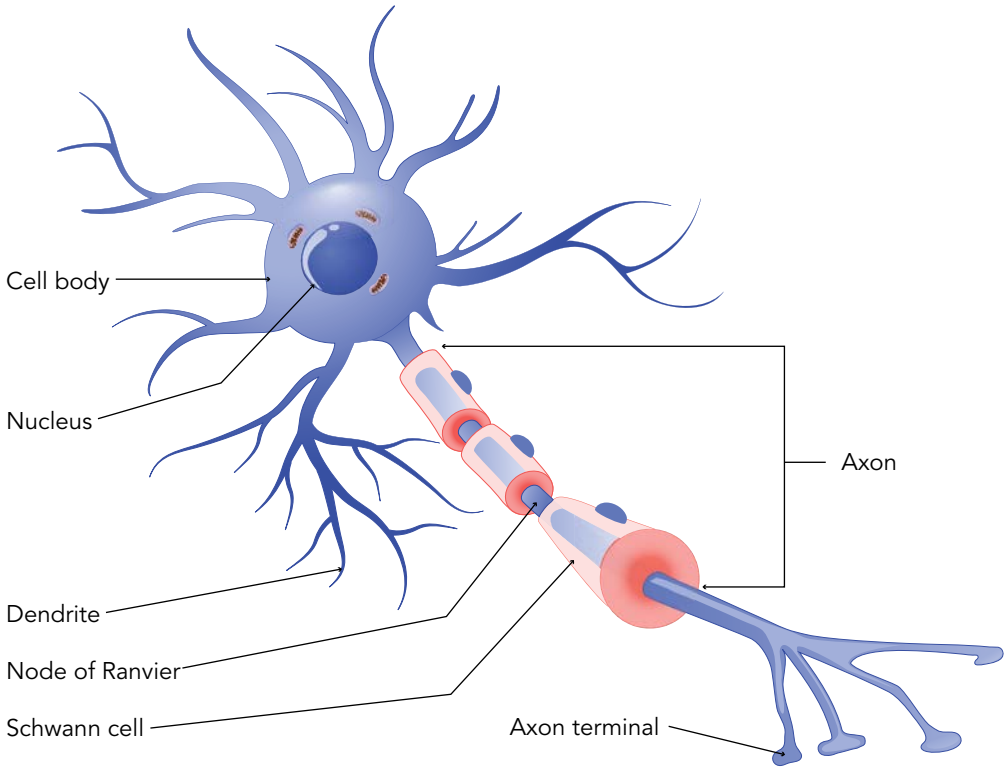
Some dendrites resemble the branches of a tree. Others have more thread-like branches, and some have branches covered with tiny spines. The reason for this branching design is simple. Remember, dendrites are the parts of neurons that receive inputs (signals). The branching pattern covers an extensive area, allowing the neuron to receive an enormous number of inputs. When an input is received by a dendrite, an electrical signal is generated and transmitted toward the cell body.

The axon is the portion of the neuron that carries a nerve impulse away from the cell body. The axon begins at a cone-shaped axon hillock on the cell body. The hillock narrows to form the more thread-like axon. The axon can be very short or up to several feet long. The axon of a motor nerve to the muscle that enables you to curl your big toe has to travel a long way, all the way from your spinal cord to your foot.

A neuron can have multiple dendrites

TAKING A CLOSER LOOK

Neuron



but only one axon. Axons end in small branches called axon terminals. At the axon terminal, neurotransmitters are released to carry the neuron's signal on to the next cell in line. You will learn more about this shortly.

Neurons — The Lowdown

There are hundreds of millions of neurons in the human body. And that's a really good thing. Why? Unlike most cell types in your body, neurons cannot be routinely replaced. Once neurons mature, with only rare exceptions, they are no longer able to divide. The neurons you have, once your nervous system matures, are all the neurons you will ever have.

So…when neurons are damaged by drugs, disease, or injury, the loss of function is often permanent. Neurons are designed to last a lifetime, but we need to take care of them. For instance, we must be vigilant about what we put into our bodies, as many illicit drugs destroy these precious messengers. A lifetime of poor eating habits and lack of exercise can increase the risk of a stroke in later life, which can destroy many neurons in the brain. Riding your bicycle without a helmet puts the irreplaceable neurons in your brain at risk right now. Following the rules for safety in contact sports may prevent a tragic accident that could leave you paralyzed. Operating power tools unsafely may lead to permanent loss of peripheral nerve function in an injured body part, even if you do not lose the body part itself. Habitually exposing your ears to loud music or explosive noise without ear protection may destroy the specialized neural structures in your ears and impair your hearing. Looking directly at the sun can permanently damage your retina, the very specialized extension of your brain that enables you to see.

God only gave you one body, and there are no do-overs when it comes to neuron damage. While many diseases and conditions that damage neurons in this sin-cursed world are not preventable, you should take care to avoid those that are.

Further, neurons require lots of oxygen and glucose to function properly. Neuron cells can be quickly damaged by lack of these essentials. Loss of oxygen for as little as four minutes can permanently damage neurons. For this reason, many people take courses in basic CPR and water safety, so that they will be able to help others avoid permanent damage or loss of life.

Performing CPR (cardiopulmonary resuscitation) on someone who has stopped breathing.

Types of Neurons

There are several types of neurons. We can classify them according to how they look or according to how they work. Each type of classification can help us understand how the nervous system works.

One method of classifying neurons is based on the number of processes they have. Remember, processes are dendrites and axons, the projections sticking out from the cell body.

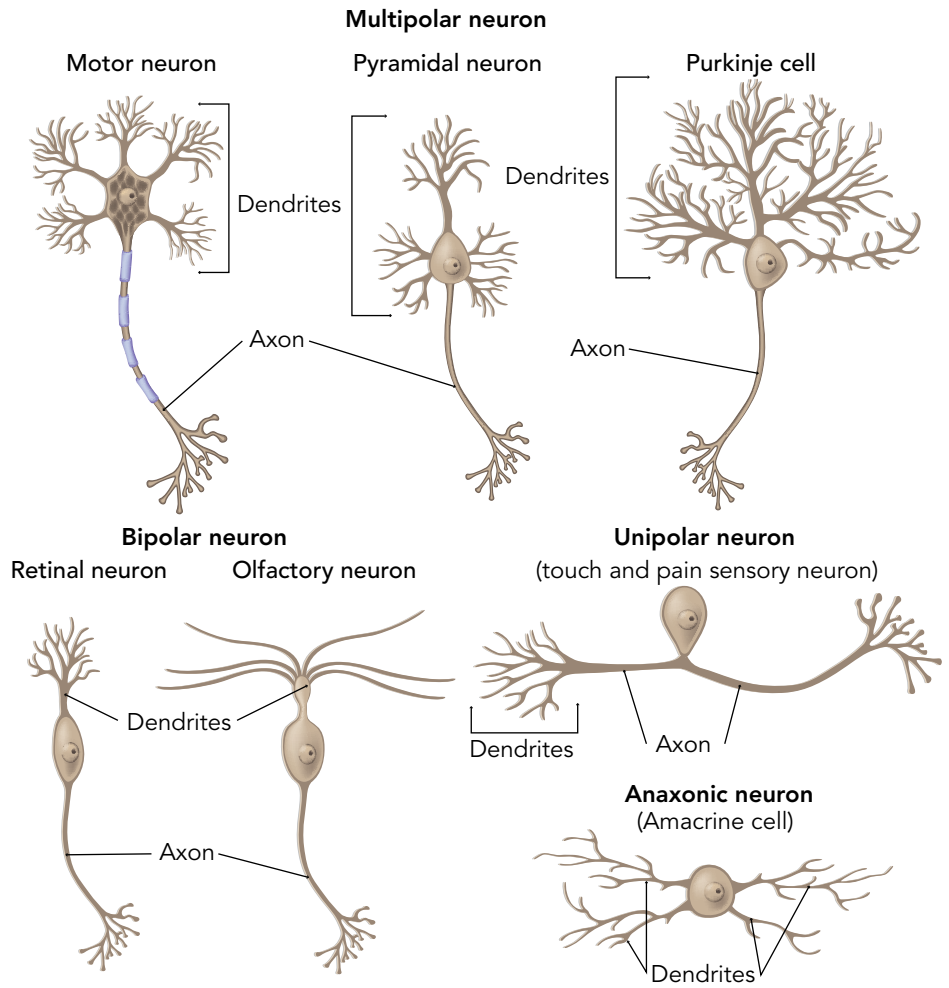
Most neurons have one axon and multiple dendrites. These are called multipolar neurons. This is by far the most common type of neuron in the body.

Bipolar neurons have only two processes: one axon and one dendrite. These are only found in special sensory organs, such as the eye, ear, and nose.

Unipolar neurons have a more unusual configuration. They have only one process extending from the cell body. This process looks like a "T." The dendrite and the axon form the arms of this "T."

TAKING A CLOSER LOOK

Types of Neurons



Neurons are also classified according to the direction they carry nerve impulses. Some neurons carry instructions from the central nervous system, and others bring information to the central nervous system.

Neurons that transmit impulses away from the central nervous system are called motor or efferent (remember "carrying away" or "carrying outward") neurons. These impulses contain instructions to muscles or to glands in the body. Most motor neurons are multipolar.

Sensory or afferent (remember "bringing toward") neurons carry impulses triggered by sensory receptors toward the central nervous system. Most sensory neurons are unipolar.

Yet one other class of neurons carries impulses from one neuron to another within the central nervous system. These connectors are called interneurons, a word that obviously means "between neurons." Interneurons make up the vast majority of the neurons in the body. Some estimates are as high as 99 percent. Interneurons are located in the brain and spinal cord, forming connections between sensory and motor neurons. Signals from sensory neurons are delivered to the interneurons. The interneurons pass the impulse on to the appropriate motor neurons. If you recall the basic functions of the nervous system, this is the integration step we discussed, a step in which inputs are processed and passed on to generate suitable output.

Neuroglia

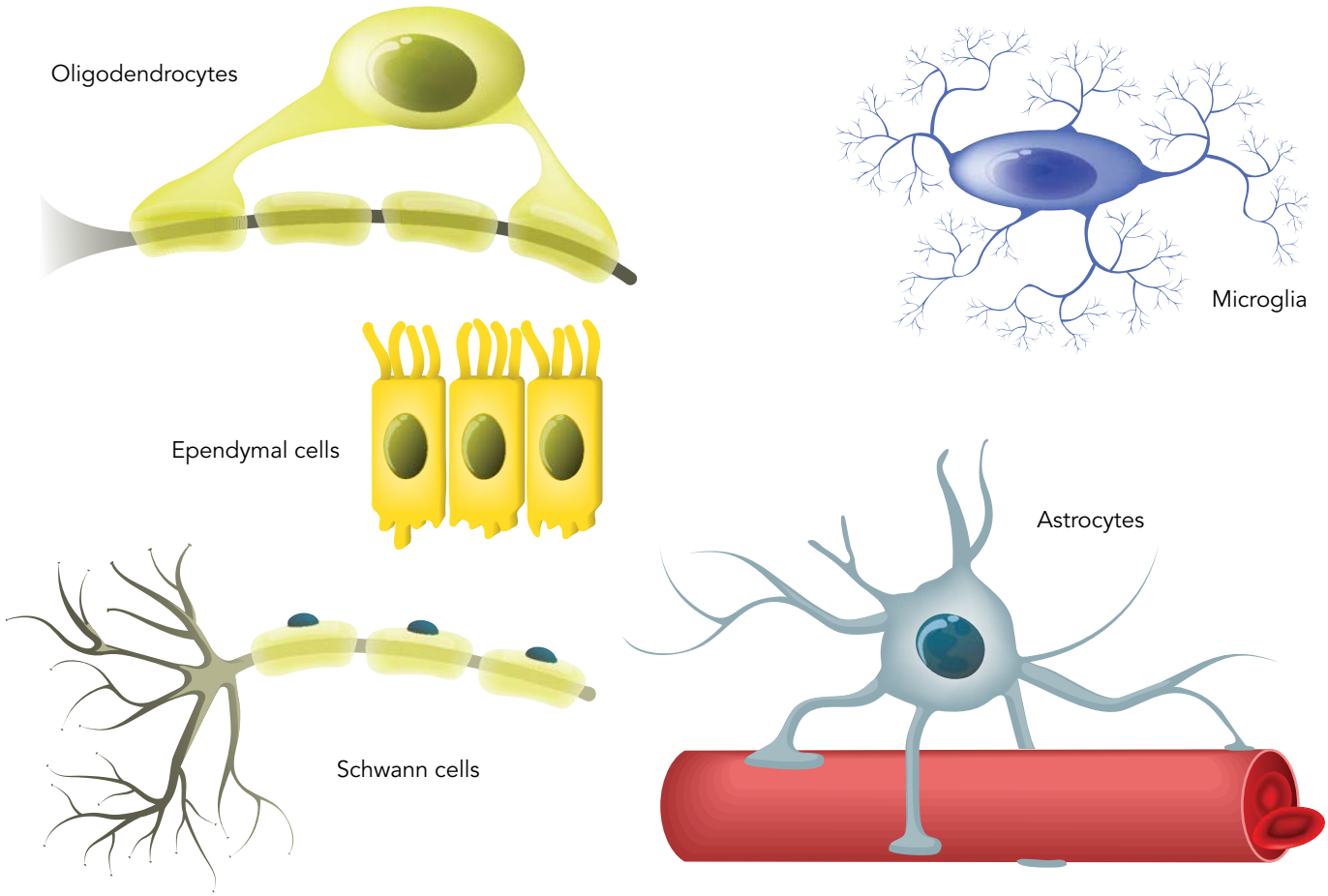
Neurons are not usually alone. They are generally surrounded by several types of smaller cells in the nervous system. These other cells are known as neuroglia, or glial cells. Neuroglia are found both in the central nervous system and the peripheral nervous system. Neuroglia have various functions depending on their cell type and location.

We will first examine the neuroglia in the CNS.

Astrocytes are the most numerous of the neuroglial cells in the CNS. Astro means "star," and cytes means "cells." Astrocytes are therefore glial cells with

TAKING A CLOSER LOOK

Types of Neuroglia



many star-shaped processes. These cells anchor and support the neurons associated with them. They help the neurons pass on impulses efficiently. Astrocytes also protect their neurons. They monitor nearby capillaries, ensuring that harmful substances in the blood do not reach the neuron. Astrocytes help maintain the correct level of ions, such as potassium (K^+), and other nutrients around the neurons. They contain a readily available supply of glucose that they supply to neurons when lots of energy is needed. They even help recycle neurotransmitters released from their neurons.

Microglia are small cells with long slender processes. (Micro means "small," so this is a good name.) Microglial cells "keep watch" over neurons in their vicinity. If they detect damage to a neuron or invading bacteria, they transform into a cell that can remove damaged nerve tissue or engulf and destroy the bacteria.

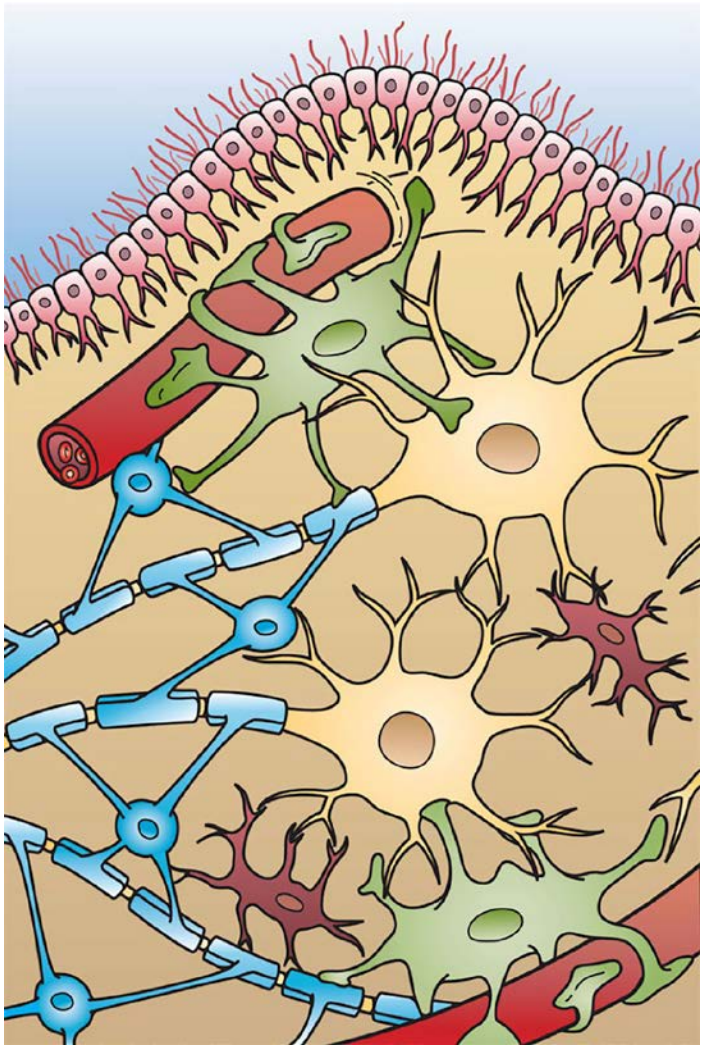
Ependymal cells line the ventricles of the brain and the spinal canal. The ventricles in the brain, like the canal surrounding the spinal cord, are filled with cerebrospinal fluid. Ependymal cells produce much of the cerebrospinal fluid that fills these cavities. Cerebrospinal fluid doesn't just sit still; it circulates through these fluid-filled spaces in the CNS. Cilia on the ependymal cells help move this fluid around.

Oligodendrocytes resemble astrocytes, but they are smaller. Oligodendrocytes produce and maintain a special covering (called a myelin sheath) around neuronal axons. This myelin sheath is made of lipids and protein. We will be learning much more about myelinated axons shortly.

Okay, now you know there are four types of glial cells in the central nervous system—astrocytes, microglial cells, ependymal cells, and oligodendrocytes. There are two types of neuroglial cells in the peripheral nervous system, satellite cells and Schwann cells.

Satellite cells surround the cell bodies of neurons in the PNS. They provide structural support and also control the extracellular environment around the cell bodies. Thus, the satellite cells function in the PNS much in the way astrocytes do in the CNS.

Schwann cells form the myelin sheaths around axons in the PNS. Therefore, Schwann cells function in the PNS the way oligodendrocytes do in the CNS. Let's explore myelination in more detail next.



This image shows the four different types of glial cells found in the central nervous system: Ependymal cells (light pink), Astrocytes (green), Microglial cells (red), and Oligodendrocytes (functionally similar to Schwann cells in the PNS) (light blue).

Myelination

Myelination is a process in which long axons are covered by a myelin sheath. The myelin sheath is a spiral wrapping of the modified cell membranes of the Schwann cells or oligodendrocytes responsible for forming the myelin. Axons having this myelin covering are said to be myelinated. Axons not having this covering are called nonmyelinated.

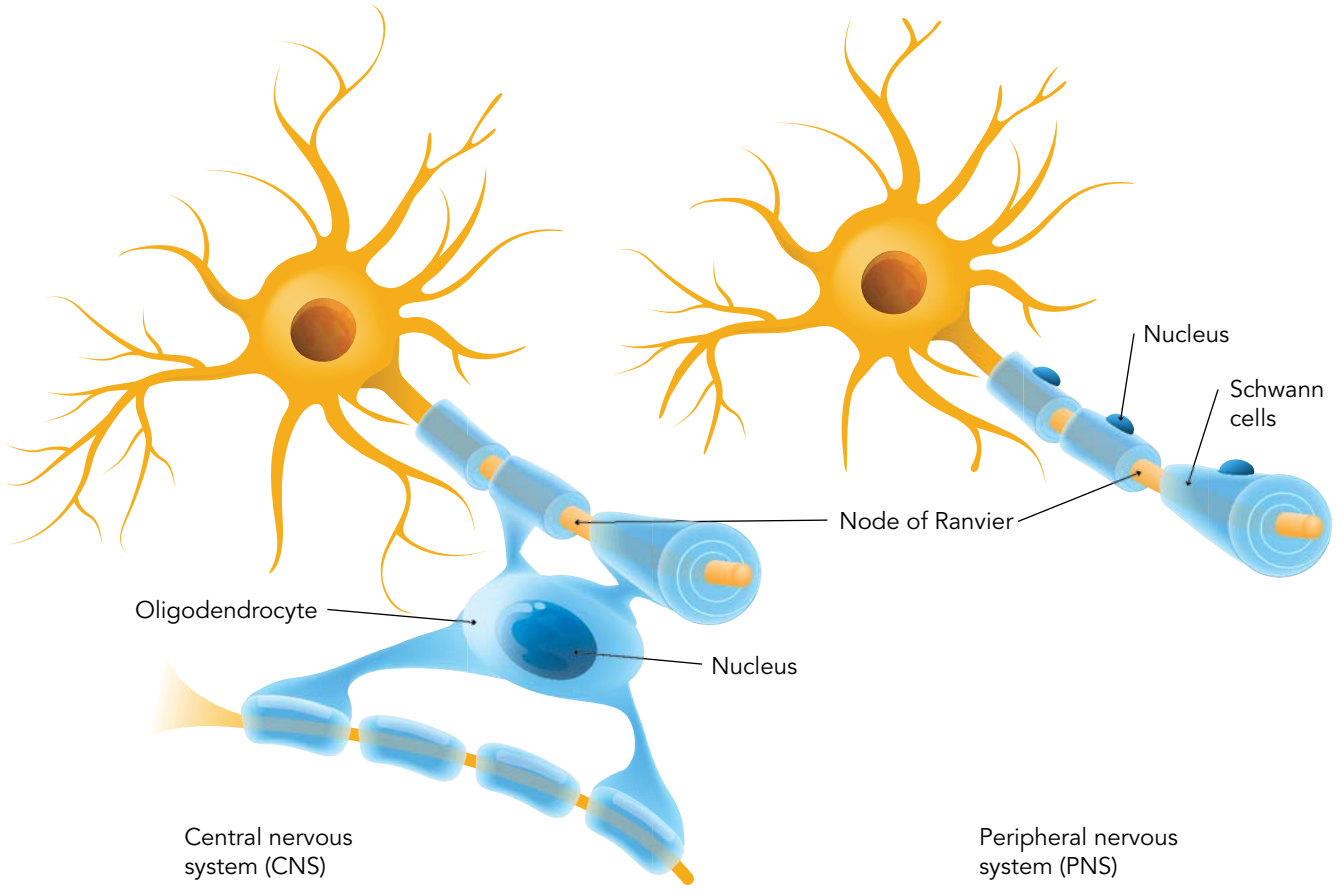
The myelin sheath provides electrical insulation for the axon. It also increases the speed a nerve signal can travel.

In the PNS, myelination is carried out by Schwann cells. These cells initially indent to receive the axon, and then wrap themselves repeatedly around the axon. Ultimately, this wrapping has the appearance of tape wrapped around a wire or gauze wrapped around a finger. At the end of the wrapping process, there may be several dozen layers of wrapping to the sheath.

Each of the Schwann cells wraps only a small length of a single axon. Other Schwann cells wrap the remaining length of the axon, like so many hot dogs in buns laid end to end. However, Schwann cells do not touch each other. There are small gaps between adjacent Schwann cells. These gaps are called nodes of Ranvier. (They were discovered by—you guessed it!—French anatomist Louis-Antoine Ranvier in the 19th century, and his name is pronounced ron'- vee-ay.)

TAKING A CLOSER LOOK

Myelination



It should be pointed out here that a Schwann cell can enclose a dozen or more axons without wrapping them. These axons are nonmyelinated even though they are in contact with a Schwann cell.

In the CNS, it is the oligodendrocyte that is responsible for myelination. Because an oligodendrocyte has many processes, it can wrap around numerous axons rather that only one, as in the case of the Schwann cell.

The amount of myelin in the body is very low at birth and increases as the body develops and matures. Thus the number of myelinated axons increases from birth throughout childhood until adulthood. Myelination increases the speed of nerve impulse conduction through the axon. Faster conduction

Multiple Sclerosis

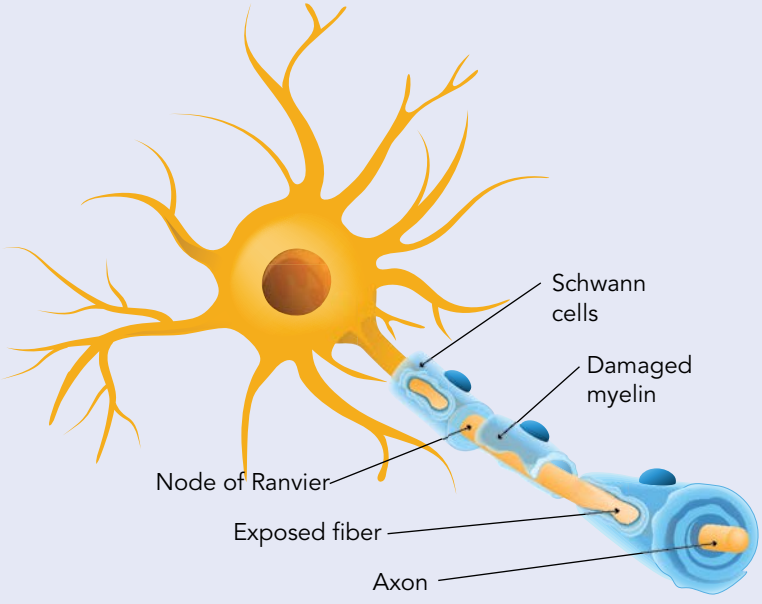
Multiple Sclerosis (MS) is an autoimmune disease that results in the destruction of myelin sheaths in the central nervous system. (In autoimmune diseases, the body's immune system turns against its owner's own tissues.) In multiple sclerosis, the body's immune system attacks myelin proteins, creating hardened lesions called scleroses. These lesions commonly occur in the optic nerve, the brain stem, and the spinal cord.

As the myelin loss increases, conduction of nerve impulses becomes progressively slower. Short circuits develop and interfere with the proper functioning of the neurons. That this disease is so debilitating shows the importance of the myelination of nerve fibers to proper functioning of the nervous system.

MS primarily occurs in people under 50 years of age. Symptoms include double vision, weakness, loss of coordination, and paralysis.

One form of MS is characterized by periods of active disease alternating with periods of minimal symptoms. Another form of MS is slowly progressive, without the symptom-free periods.

Although in recent years much progress has been made in our understanding of multiple sclerosis, at present there is still no cure.



makes those nerves work better, more efficiently, as an individual matures.

Think of a newborn baby. It has very little control of its body in the beginning. It cannot hold its head up or sit up or walk. As more axons become myelinated, it has more and better control of its muscles. Compare this to a teenager. After years of development, the teenager has much better control and coordination of the body. Much of this improvement of due to increased myelination both in the central and peripheral nervous systems.

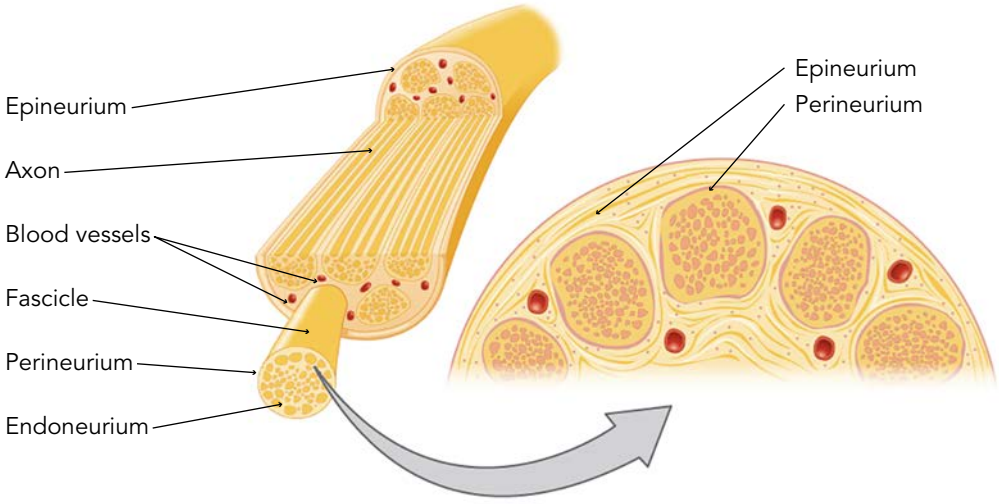
Nerves

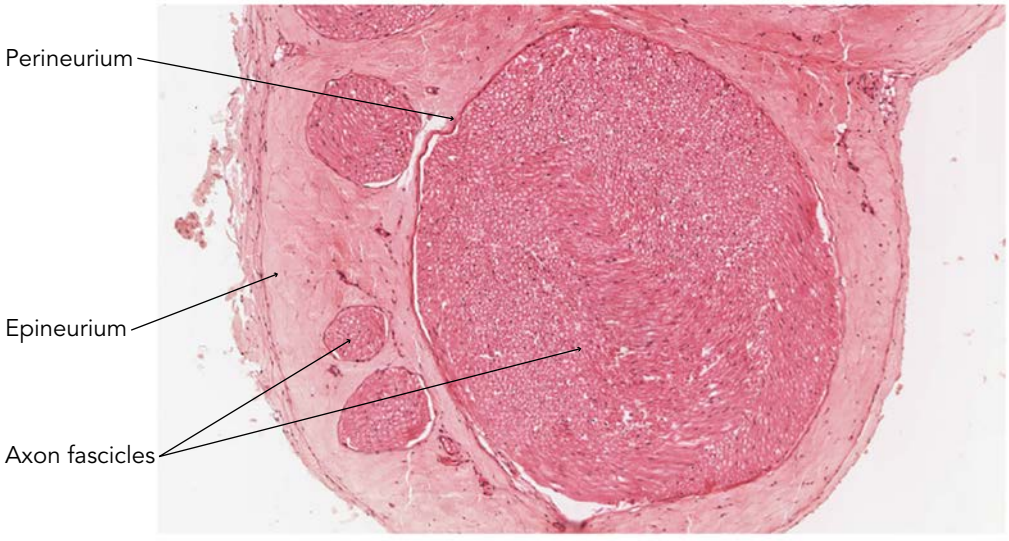
What are nerves? They not the same thing as neurons.

A neuron is a nerve cell. Neurons have dendrites and axons. The neuron is the cell that transmits electrical impulses in the nervous system. Thus, the neuron, not the nerve, is the basic unit of nervous tissue.

TAKING A CLOSER LOOK

Anatomy of a Nerve





So what is a nerve? Well remember that axons, even though they are part of nerve cell, can be very long. Some reach from your back to your foot. A nerve is made of bundles of axons located in the peripheral nervous system. These bundles of axons are not alone in the nerve. The nerve also contains the Schwann cells associated with the axons, as well as blood vessels, connective tissue, and lymphatic vessels. This cross section shows the various components.

Before we go further, let's see how some of these things fit together.

Individual axons and their associated Schwann cells are covered by a very thin layer of connective tissue known as the

endoneurium (endo- meaning "inner," and neurium meaning "nerve"). Next, many such endoneurium-covered axons running parallel to each other are grouped in bundles called fascicles. Each fascicle is then covered by another connective tissue layer known as the perineurium (peri- meaning "around"). Lastly, numerous fascicles, blood and lymphatic vessels are bound together by yet another connective tissue wrapping called the epineurium (epi- meaning "over"). This epineurium-wrapped bundle of bundles—containing axons, neuroglia, blood vessels, lymphatic vessels, and layers of connective tissue—is known as a "nerve."

Remember that neurons can be classified by the direction they carry electrical impulses. Motor neurons carry impulses away from the central nervous system, and sensory neurons carry impulses toward the central nervous system. Nerves can be classified the same way.

Motor nerves carry signals away from the CNS. Sensory nerves carry impulses toward the CNS. But motor nerves and sensory nerves are very rare. The most common type of nerve by far is called a mixed nerve. Even though an individual neuron can only carry an impulse in one direction (remember, from dendrite to cell body to axon), mixed nerves possess both motor and sensory fibers. Mixed nerves have two-way traffic. They carry impulses both toward and away from the CNS.

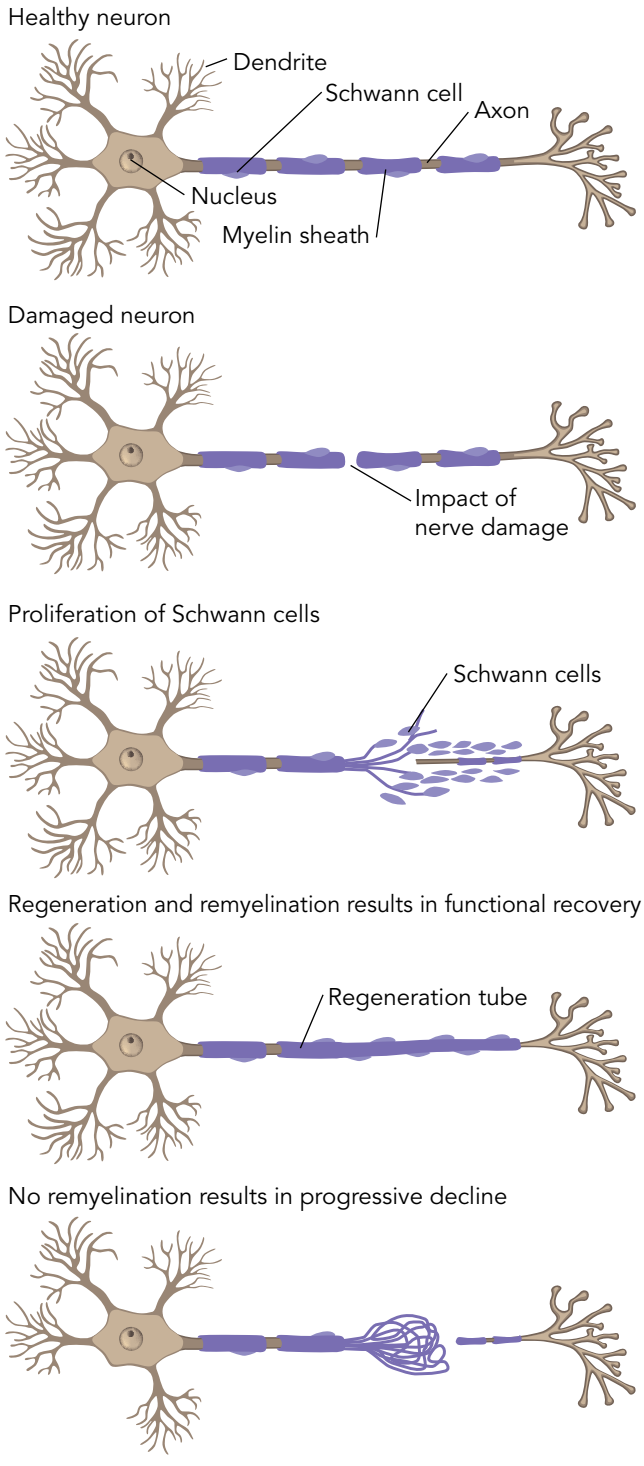
Nerve Damage and Repair

With rare exceptions, mature neurons do not divide to reproduce themselves. The mature nervous system is not designed to replace damaged nerve cells. The neurons you have now are pretty much all you are going to get. Because of this, damage to the nervous system is serious.

However, there is a bright spot here. In the peripheral nervous system, there can be regeneration of a nerve after an injury. Recall that a nerve does not contain whole neurons, but instead consists of bundles of axons and their supporting tissues.

TAKING A CLOSER LOOK

Neuron Damage and Repair



When a nerve is badly damaged, proteins and other vital substances produced in the neuron cell bodies cannot be transported all the way out to the ends of their axons. The distal (farther away) portions of the axons—the part beyond the injury—begin to break down without these nutrients. This is known as Wallerian degeneration. However, the Schwann cells near the injured area multiply and begin to form a protective tube. This "tube" helps align the damaged ends of the axons as they regenerate. Further, the Schwann cells secrete growth factors to promote axon regeneration. Therefore, nerve damage in the PNS does not always result in permanent loss of function.

It is a different story in the CNS. Recall that myelination in the CNS is due to the presence of oligodendrocytes. Unlike the Schwann cells in the PNS, oligodendrocytes do not have the capability of supporting regeneration of a damaged axon. For this reason, damage to the brain or spinal cord is more serious and more likely to be permanent than peripheral nerve injury.

The foundation of our thinking in every area of our lives should be the Word of God.

How we understand the world, how we approach our daily tasks, how we view and treat our fellow man — these things should be based on the principles we find in the Bible.

Unfortunately, too many people are so strongly influenced by the views of the world that they reject the direct teaching found in God's Word. These people view the world around them as just a chemical accident. Matter somehow just came into existence all on its own billions of years ago. Then everything in our world just created itself. Millions of years of chemicals banging together resulted in something as incredibly complex as the human body.

Even though we've only just begun our study of the nervous system, I'll bet you are already getting the idea of how complex just this one body system truly is. Do you really think it could have just created itself, all on its own? No, neither do I.

In the Book of Genesis, we are told

> In the beginning God created the heavens and the earth (Gen. 1:1).

There is an all-powerful God who indeed created all things. The earth, the living creatures, the sun and moon, the planets, the stars in the sky—these things did not come into being as the result of an accident. They are not the result of time and chance. They are the work of our wonderful Creator.

Even more, you and I are not the products of chance. We are special creations.

> Then God said, "Let Us make man in Our image, according to Our likeness" (Gen. 1:26a).

As we continue our study of the human body, we need to always remember that the complex systems we study bear the unmistakable mark of the Master Designer. The enormous complexity of the body should remind us constantly of God's wisdom and creativity. We should also be reminded of His boundless love for us that He should take such care in our creation.