JR. HIGH STUDENT

VOL. 2

INTRODUCTION TO ANATOMY & PHYSIOLOGY

Cardiovascular and Respiratory Systems

wonders of the HUMAN BODY

Dr. Tommy Mitchell

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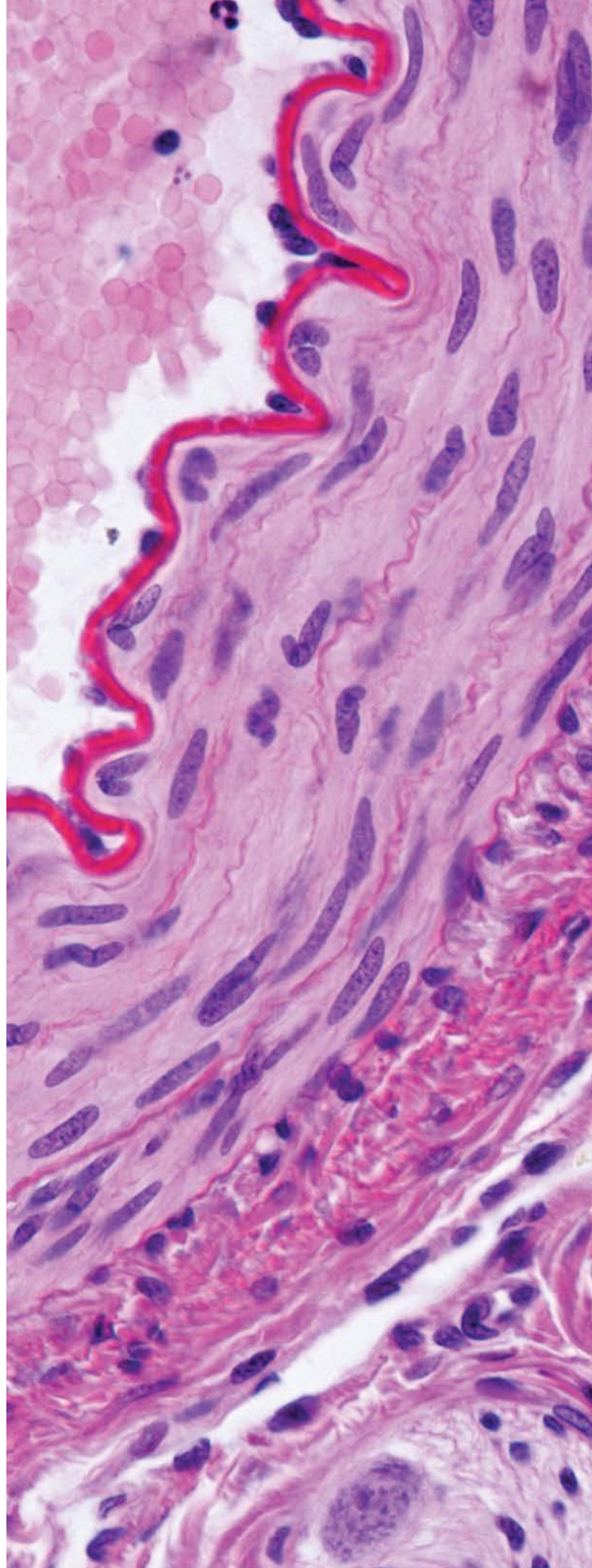
Dedication

For my three beautiful daughters,
Mary, Ashley, and Sarah



Light micrograph of a cross-sectioned muscular artery, showing a thick and wavy internal elastic lamina, a middle layer with smooth muscle fibers, and an outer connective tissue adventitia.

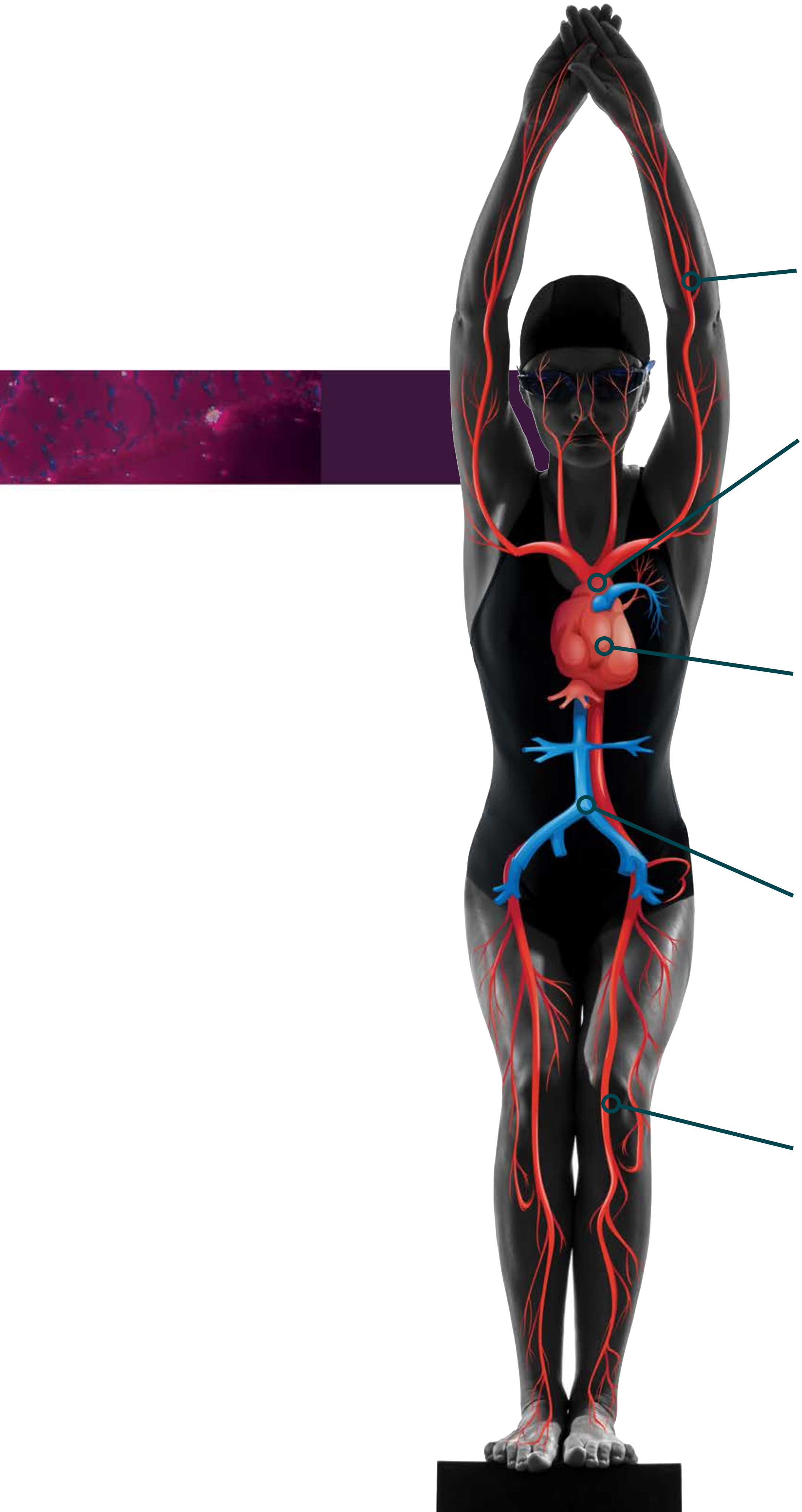
TABLE OF CONTENTS

SECTION 1

THE CARDIOVASCULAR SYSTEM

The heart must ceaselessly move blood around your body to keep you alive. It pushes that blood through a system of blood vessels. Those vessels branch out to carry blood all over your body, making oxygen, nutrients, water, and dissolved electrolytes available to every cell in your body. They also carry away waste materials for disposal or recycling. The heart, with all its associated vessels, is called the cardiovascular system. This name — cardiovascular — is one of those anatomy word puzzles: cardio- means "heart" and vascular means "vessels."

For You formed my inward parts;
You covered me in my mother's womb.
I will praise You, for I am fearfully and wonderfully made;
Marvelous are Your works,
And that my soul knows very well.
My frame was not hidden from You,
When I was made in secret,
And skillfully wrought in the lowest parts of the earth.
Your eyes saw my substance, being yet unformed.
And in Your book they all were written,
The days fashioned for me,
When as yet there were none of them.
(Psalm 139:13-16)



In one year your heart pumps enough blood to fill an Olympic sized swimming pool!

The first human to human heart transplant was preformed by Dr. Christiaan Barnard on December 3, 1967.

The heart generates its own electrical signals. It can beat even if taken out of the body!

Your heart began beating 22 days after you were conceived. It beat about 54 million times before you were born!

Bone marrow helps to create red and white blood cells, and these help us in many ways, including fighting bacterial You have around 60,000 miles of blood vessels in your body. That’s enough to circle the Earth twice with 10,000 miles to spare!

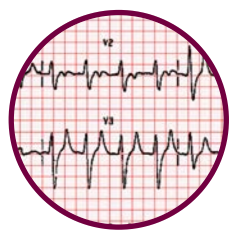
1

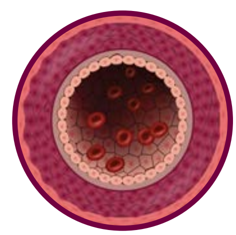
INTRODUCTION

Have you heard your heart beat or felt your pulse? Have you ever blown up a balloon or had your milk "go down the wrong way"? Do you have any idea why people sneeze or cough?

Do you have a friend with asthma? Do you know what a heart attack is? Has someone in your family had heart surgery? Have you wondered how CPR works? Wouldn't it be great to know these things?

The purpose of this book is to explain how God's amazing designs enable your heart and lungs to move blood and oxygen around in your body for a lifetime. Once you understand how these systems work, you'll be able to understand many of the things that go wrong with them and the things you can do to keep yourself as healthy as possible.





The human body is a collection of organ systems which all work together to keep you going. Your heart, lungs, kidneys, stomach, and liver are examples of organs. An organ system is a group of organs working together to do an important job. Your circulatory system consists of all the parts of your body that move blood around. The heart and many blood vessels, large and small, make up your circulatory system.

Another system, the respiratory system, gets oxygen from the air; you need oxygen to live. The respiratory system also gets rid of the carbon dioxide your body makes. The respiratory system consists of the lungs and all the tubes (called airways) that air must travel through.

The circulatory (or cardiovascular) system and the respiratory system work together. The oxygen your lungs obtain from the air must be carried to all parts of your body, even into the tiniest places far from your lungs. How these systems work together so precisely is a testimony to our marvelous Creator, the One who designed our bodies with great care.

How We'll Proceed

The body has many organ systems that will be the subjects of other books in this series. But since all parts of the body work together, we'll mention other organ systems a lot. For example, your brain and nervous system help control your respiratory system. We'll talk a little about those systems whenever we need to right here in this book, and then you can learn more about the other systems later in the other books in the Wonders of the Human Body series.

When we learn about an organ system, we first will show you its parts and learn their correct names. Learning the names for things in science is like a puzzle: a lot of the names are built of little words and syllables which help you guess and remember the names of other things in science. We'll use lots of pictures and illustrations to show you anatomy — the way your parts are put together.

Organs are made of tissues, and tissues are made of cells. Sometimes we will show you pictures of what those tissues and cells look like under a microscope, amazing details too small to see with the naked eye. Those "photomicrographs" not only show you the anatomy but also help us to understand how the organs work.

Once you see the anatomy of an organ system and know its parts, you'll be able to understand how the system works. How the systems work is called physiology. When you finish this book, you'll know where the organs are (anatomy), how they work (physiology), and what you can do to keep them healthy.

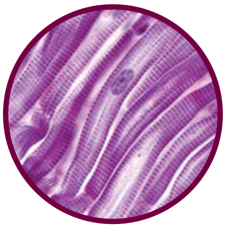
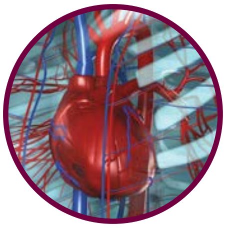
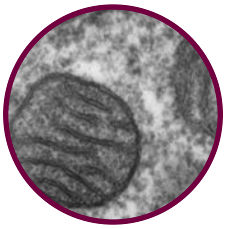
Often, learning about what happens when things don't work right helps us understand how organ systems work in the first place, so we'll discuss some diseases and how they affect the heart and lungs.

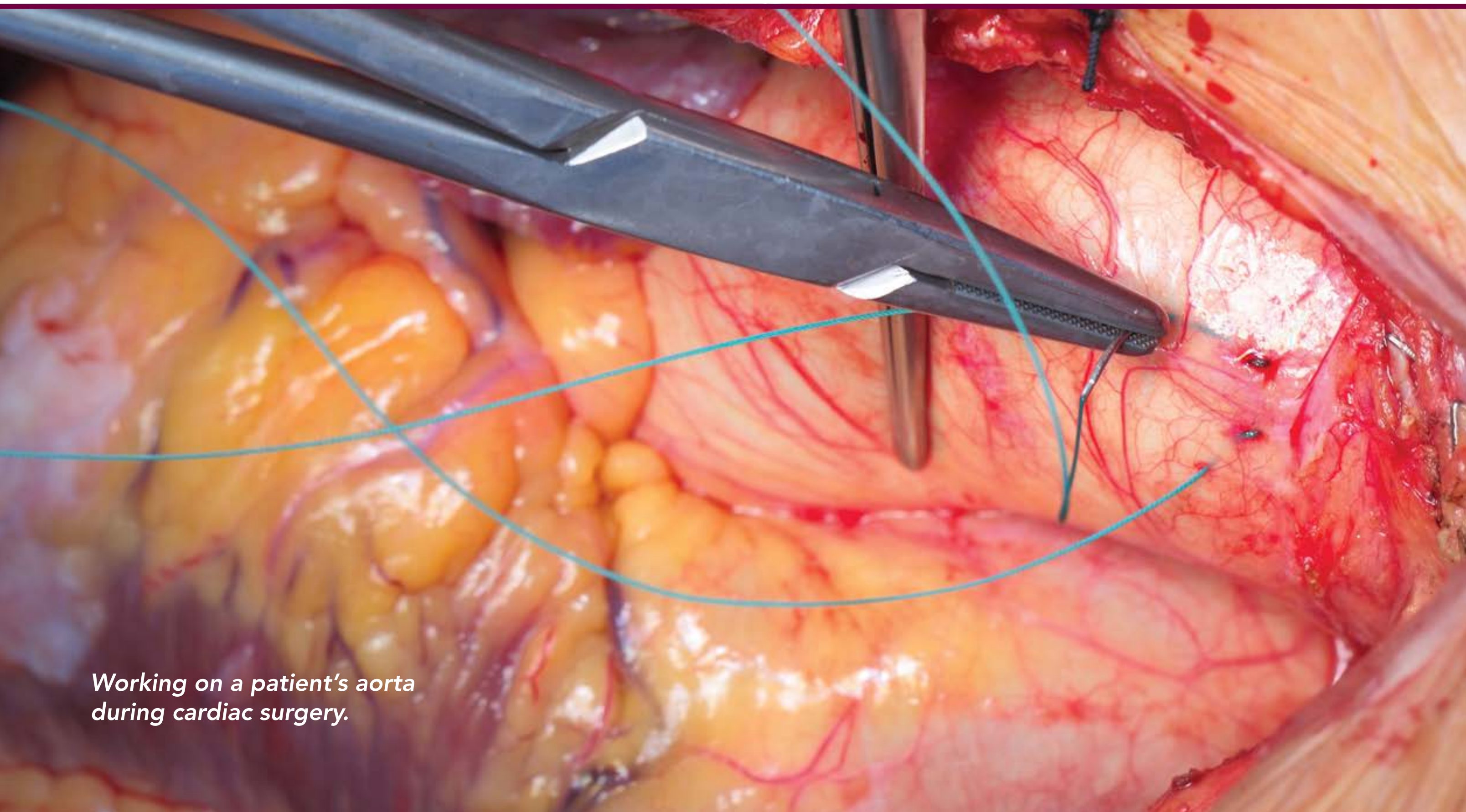
In the Beginning . . .

You may have heard that the incredible systems in your body evolved little by little over millions of years, but in fact, God created them perfect and complete in the first man and woman, Adam and Eve, about 6,000 years ago. Their hearts and lungs would have worked perfectly forever if they had not sinned, but disobeying God caused disease and death to enter a perfect world. When we learn about diseases, we are learning about the many things that have gone wrong in the world since Adam and Eve first sinned. In this book we'll talk a lot about the heart that moves your blood around, but in the Bible you can learn about another kind of heart — not the physical heart that beats in your chest, but the invisible heart that can believe in Jesus Christ. Look in the Book of Romans, chapter 10, verse 9. God wants you to pay attention to both kinds of heart.

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?

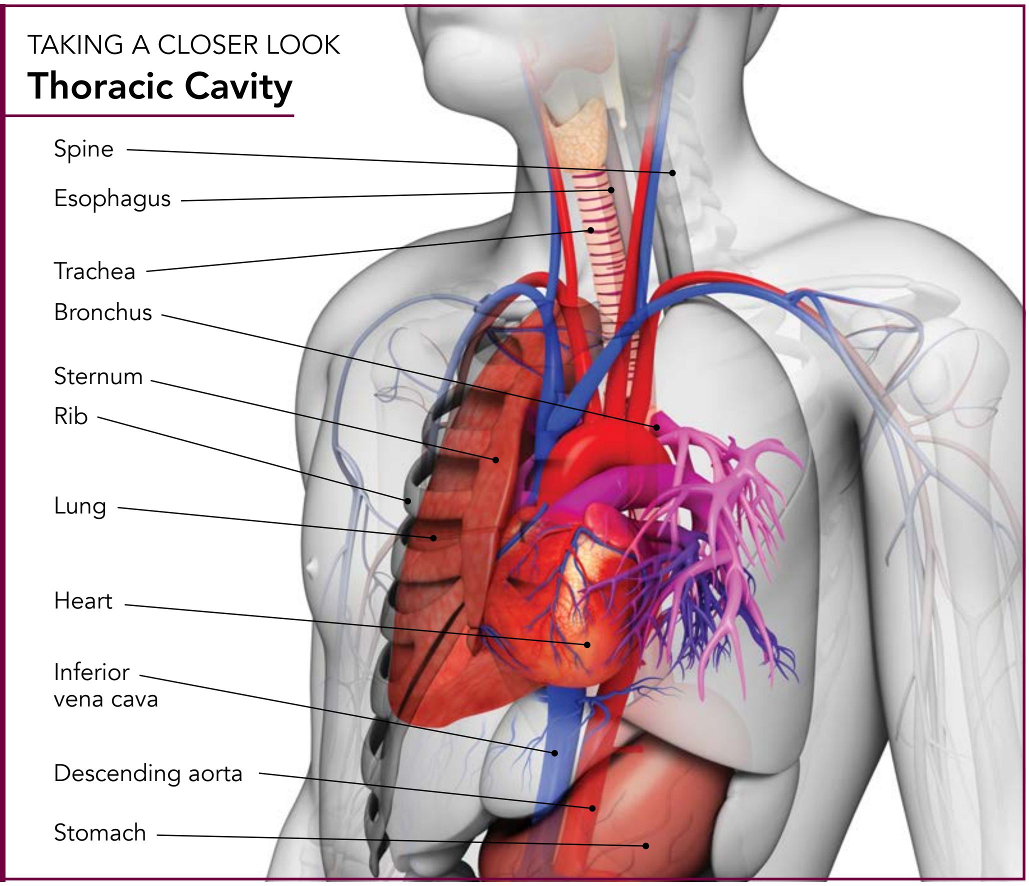
Location of the Heart

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!

TAKING A CLOSER LOOK

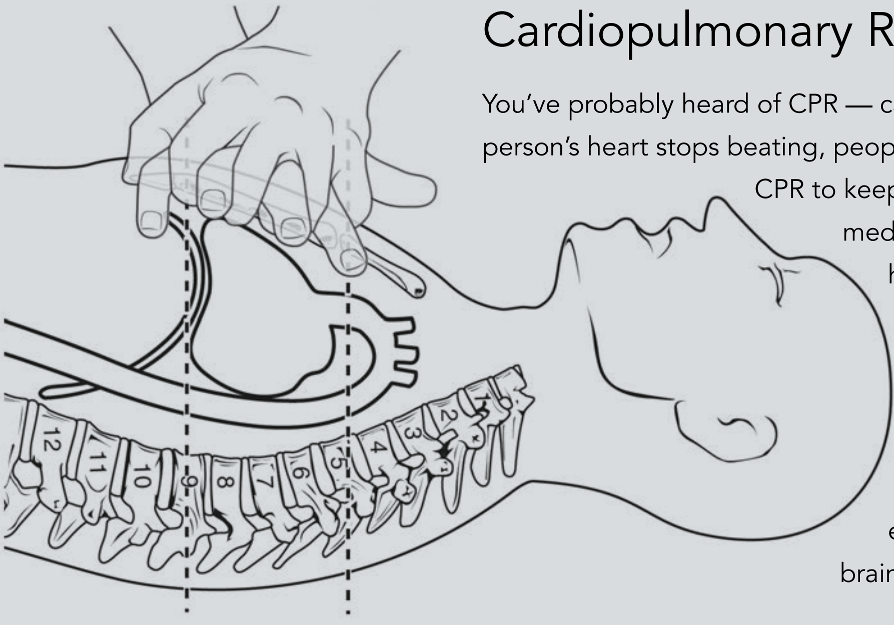
Thoracic Cavity



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*.

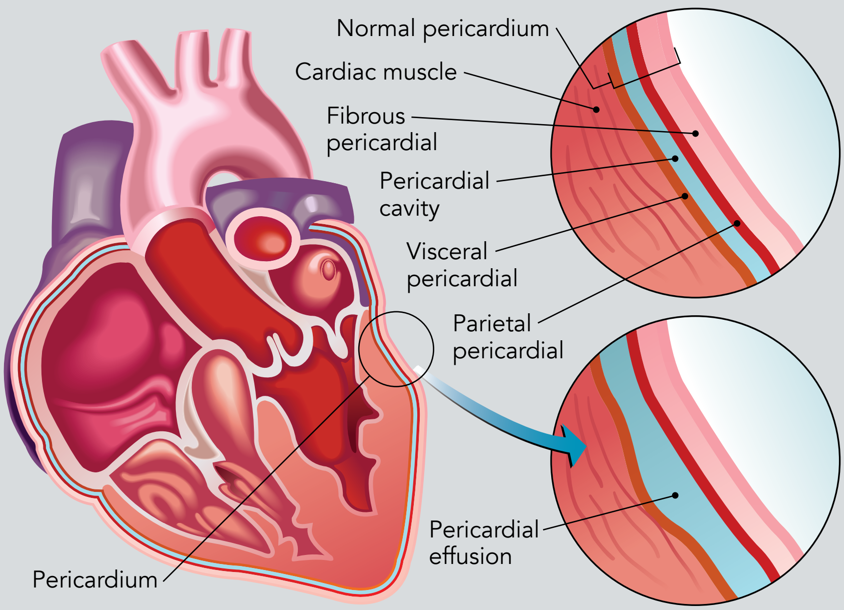
The fibrous pericardium is composed of tough, inelastic connective tissue. It serves to protect the heart, and to hold the heart in position in the chest.

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

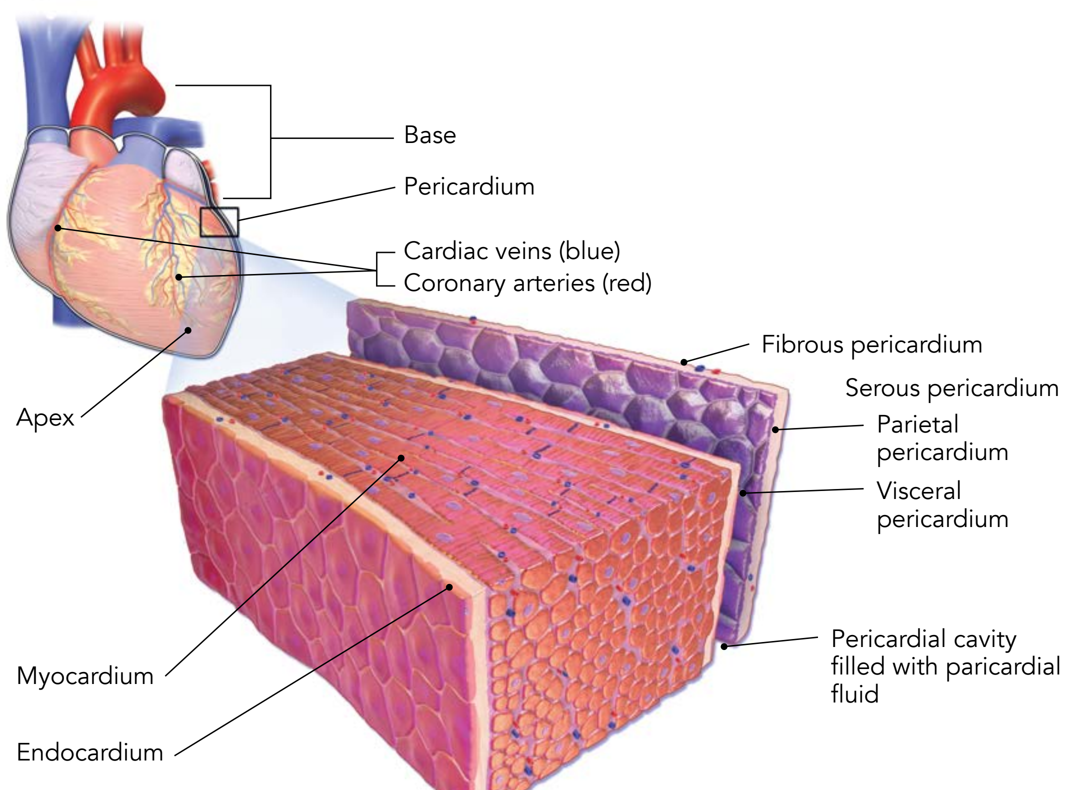
The wall of the heart consists of three layers: the *epicardium*, the *myocardium*, and the *endocardium*. Now you can see how thinking of anatomical names as word puzzles can help you! *Peri*, as in "pericardium," means "around," and the pericardium surrounds the heart. *Epi* means "outer," *myo* means "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.

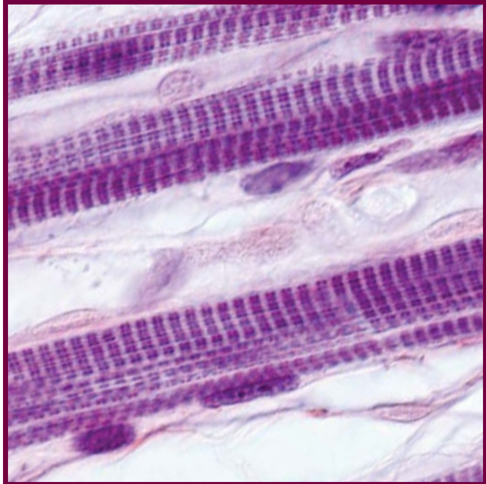
Cardiac Muscle

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

In Volume One of *Wonders of the Human Body*, you 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.

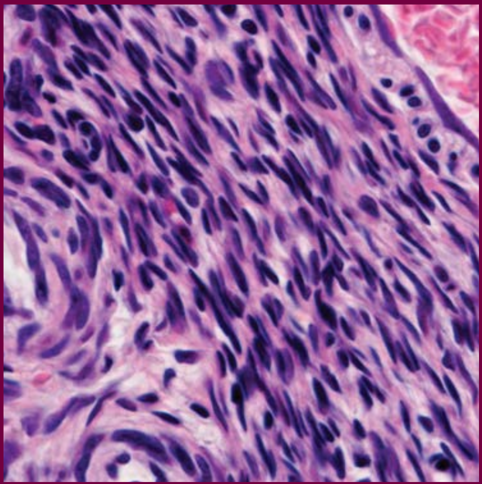
Like skeletal muscle, cardiac muscle is striated. However, the striations are not as easily seen in cardiac muscle. Cardiac muscle cells are shorter and fatter than skeletal muscle cells. Also, cardiac muscle cells branch and connect with one another in a somewhat irregular pattern. Like all cells, cardiac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

Muscle Tissue Types



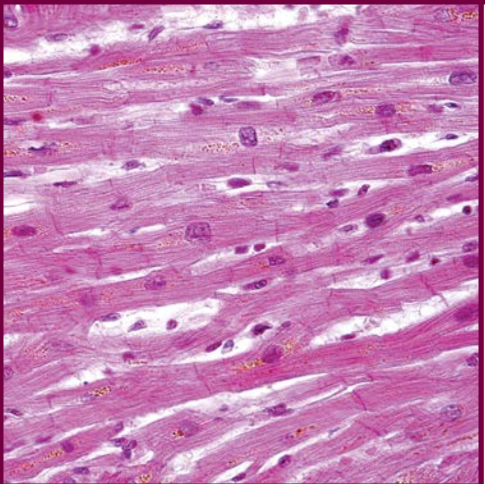
Skeletal Muscle Tissue

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.



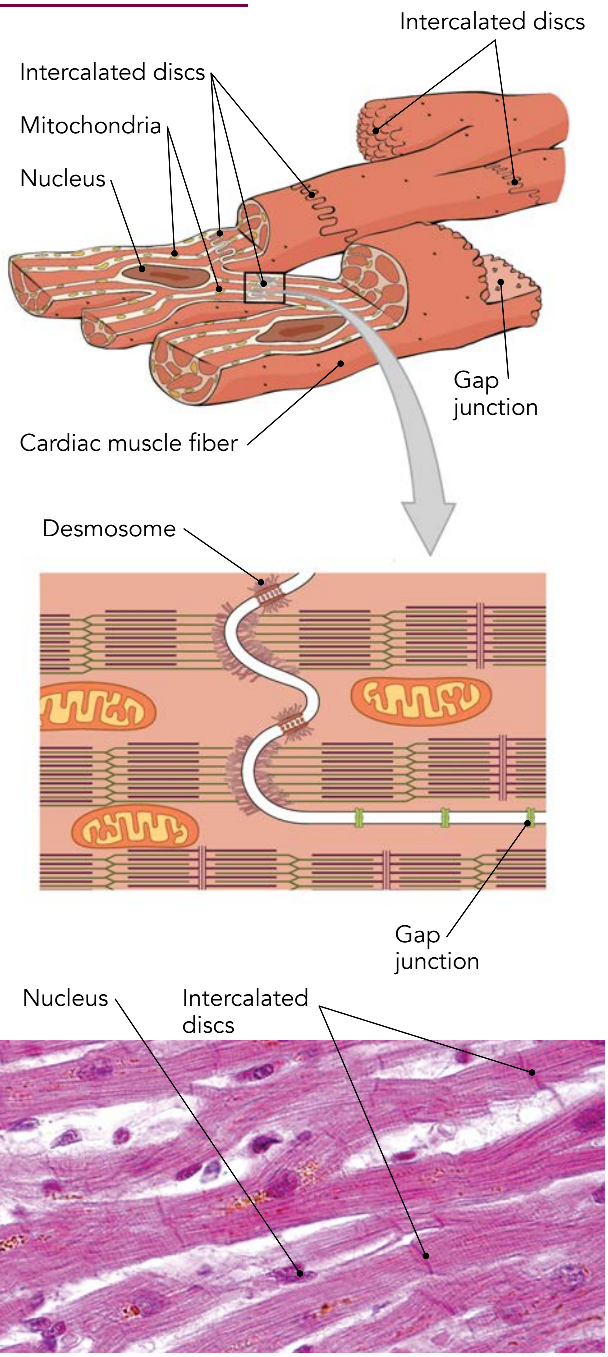
Cardiac Muscle

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.

(also called a cell membrane). At the end of cardiac 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.

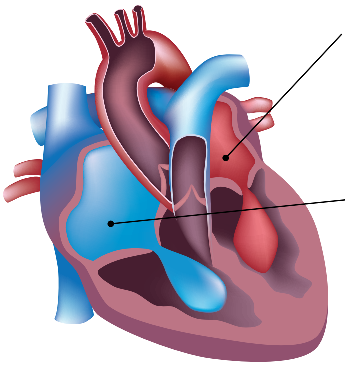
Vessels carrying blood *toward* the heart are called *veins*. Now you know that both oxygenated and deoxygenated blood can be carried in arteries. What about veins? The same is true. Some large veins (called *vena cavae* — a word that means big "cavernous" veins) carry deoxygenated blood back to the 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.

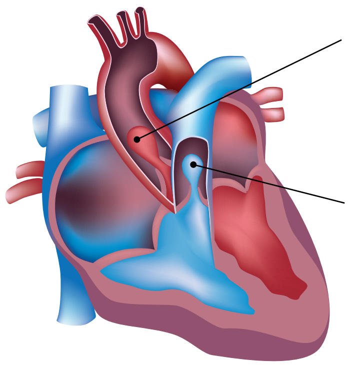
Confusing, right? Well, we will try and give you a hand.

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





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?

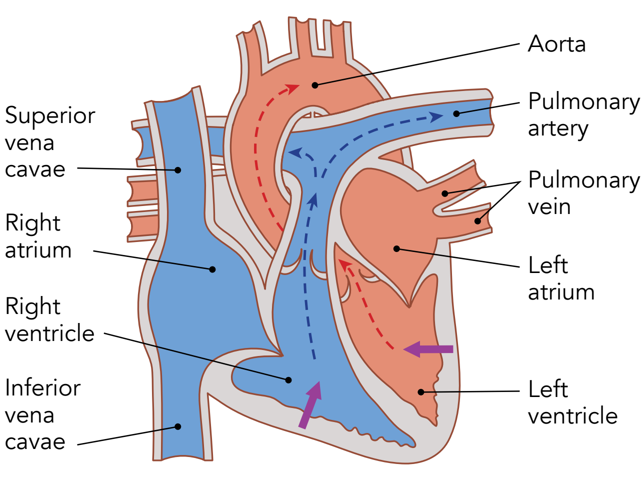
The right and left atria collect blood and then send it on to the ventricles. As the atria fill, the pressure within the atria rises as a result of the increasing amount of blood. Then, when the ventricles relax, this pressure starts pushing blood from the atria

1 Deoxygenated blood returns to the heart via the superior and inferior vena cavae.

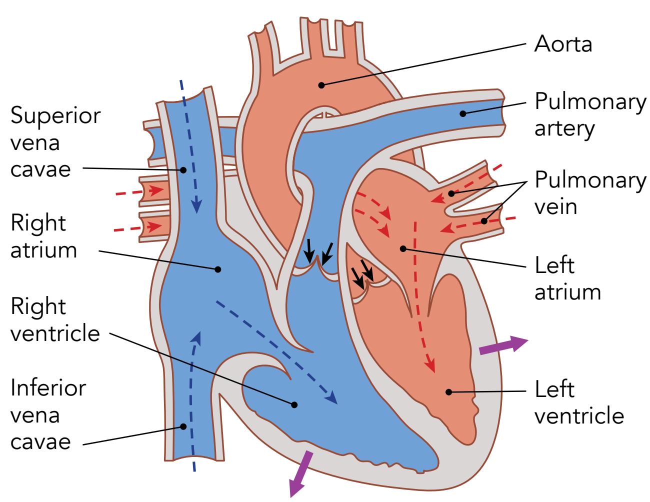
2 Oxygenated blood returns to the heart from the lungs through the right and left pulmonary veins.

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.

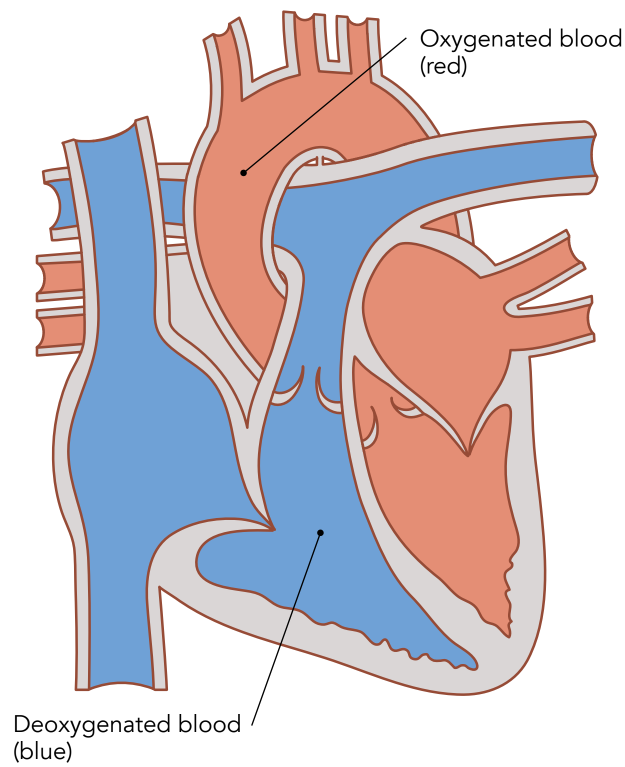
Pattern of Blood Flow

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.

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

TAKING A CLOSER LOOK

Oxygen-rich vs Oxygen-poor Blood



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

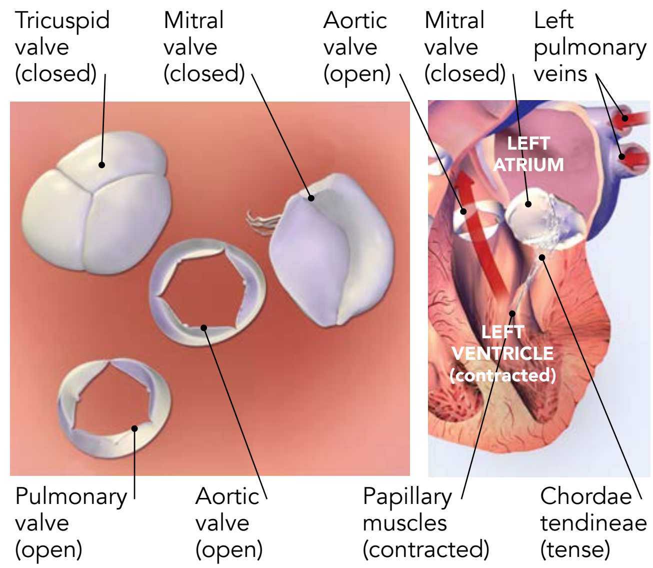
You know that most of the rooms in your home have doors. It is obvious why those doors are there. But are there rooms that don't have doors? Those rooms were designed for a reason. The rooms that have no doors allow access in and out much more easily, right? On the other hand, you've probably seen businesses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

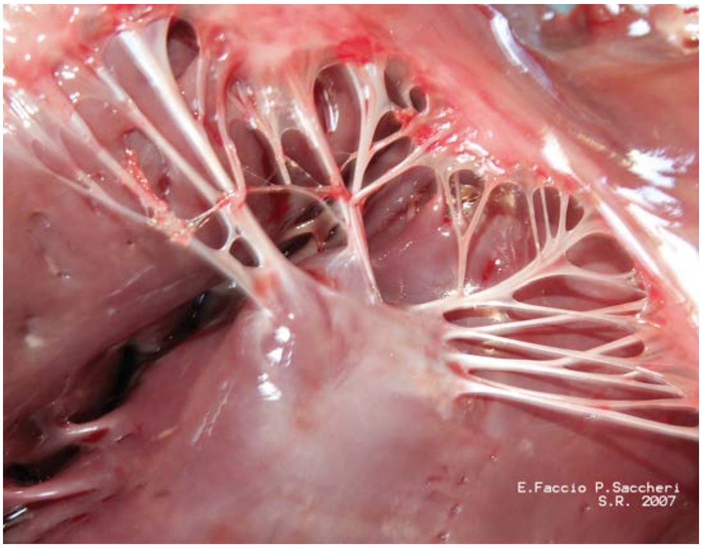
Which design do you think would work best for the heart's "rooms," its chambers? What would happen to the blood in the ventricles when the ventricles squeezed if the heart's rooms had no doors? If you said some blood would go backward into the atria, you see the problem. The ventricles would waste much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

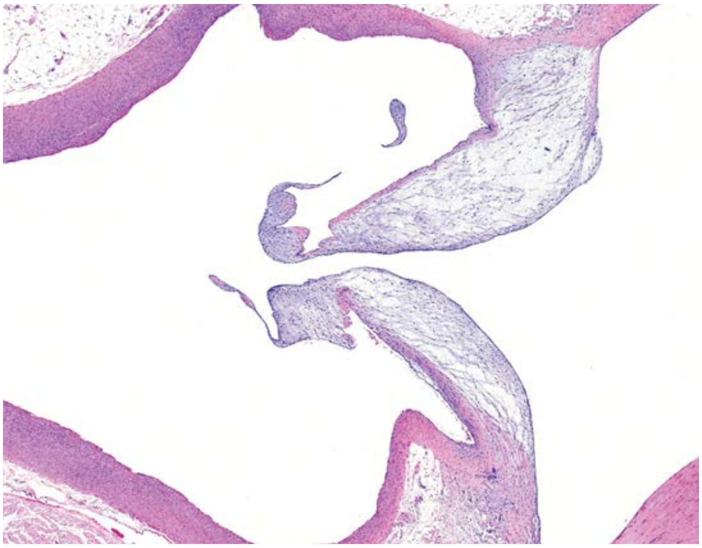
TAKING A CLOSER LOOK

Valves of the Heart





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.

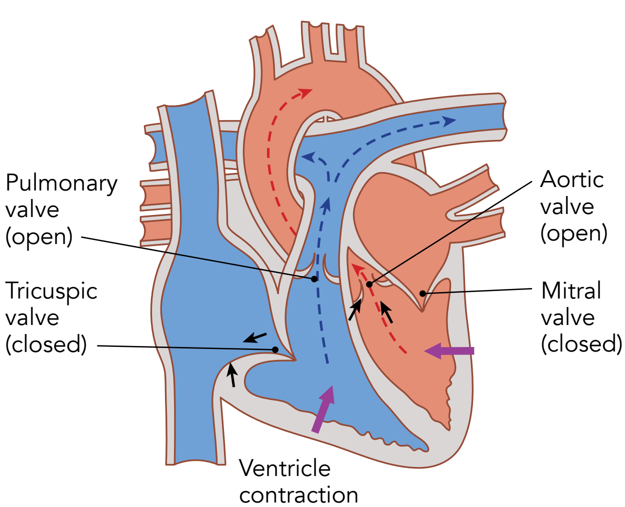
If these cusps were not secured to the walls of the ventricles, the high-pressure blood filling them would push back into the atria. The cusps are therefore tethered to the ventricular walls. The ties that bind these cusps to the ventricular wall are called *chordae tendineae*. This Latin name means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

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?)

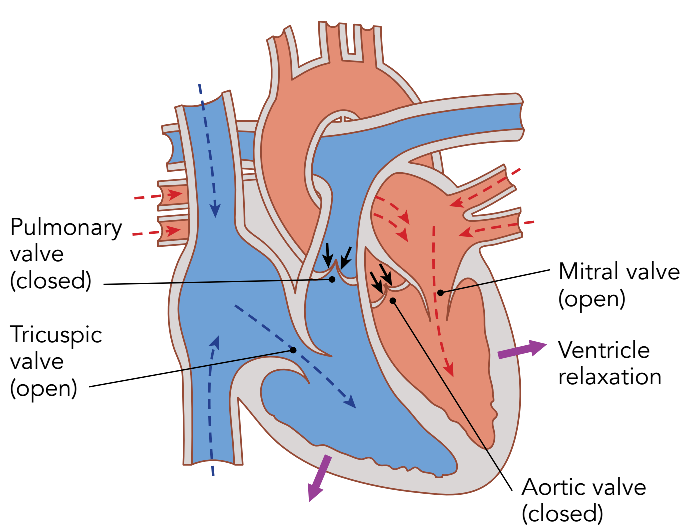
The heart's valves do not require a doorman to close them. The pressure of the blood inside the ventricles pushes them shut. We could even say the pressure makes them slam shut. But they make no noise. You've probably heard that the heart makes a "lub-dub" sound with each beat. The "lub" sound comes 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.