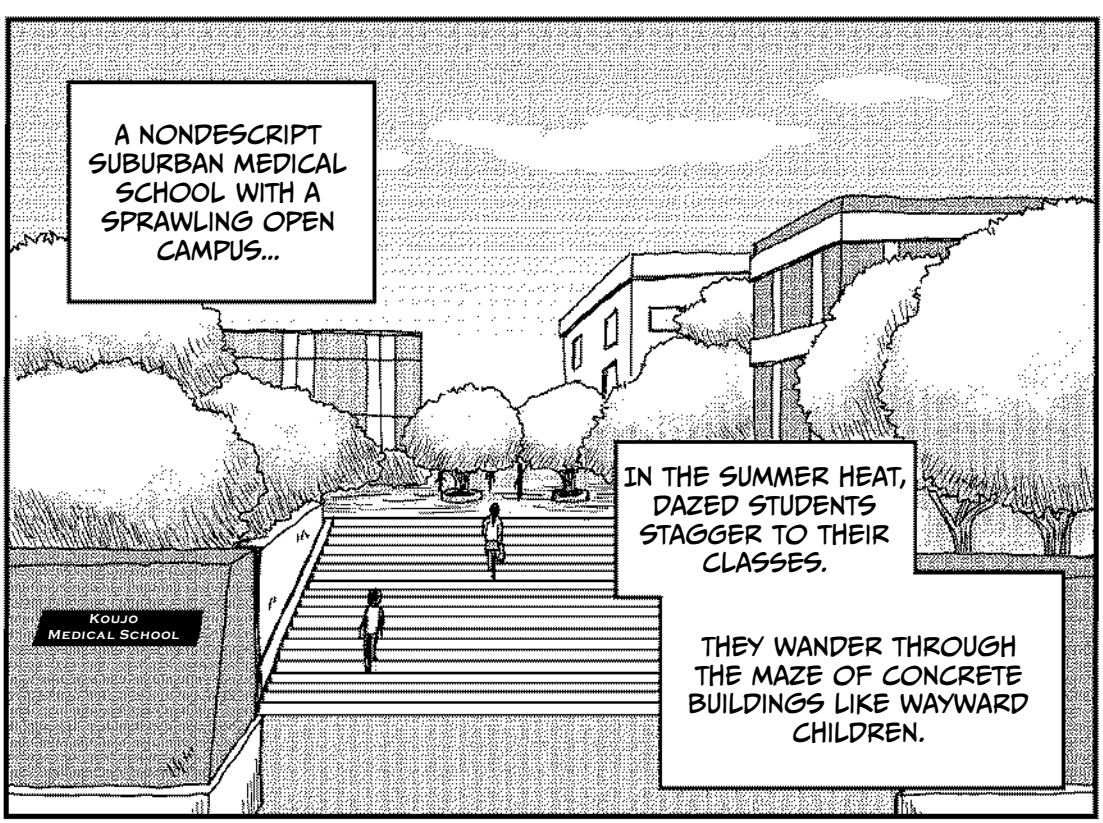
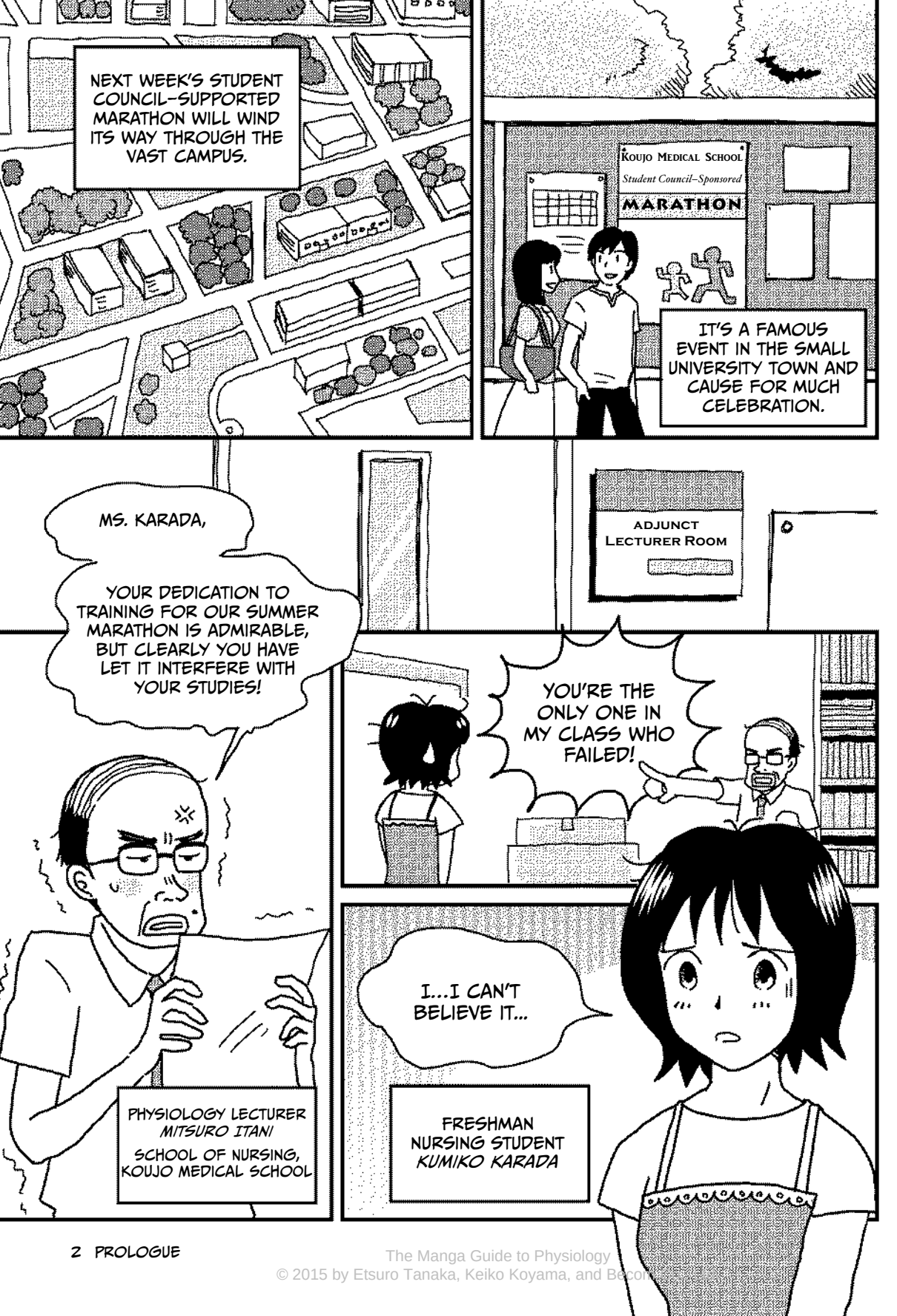
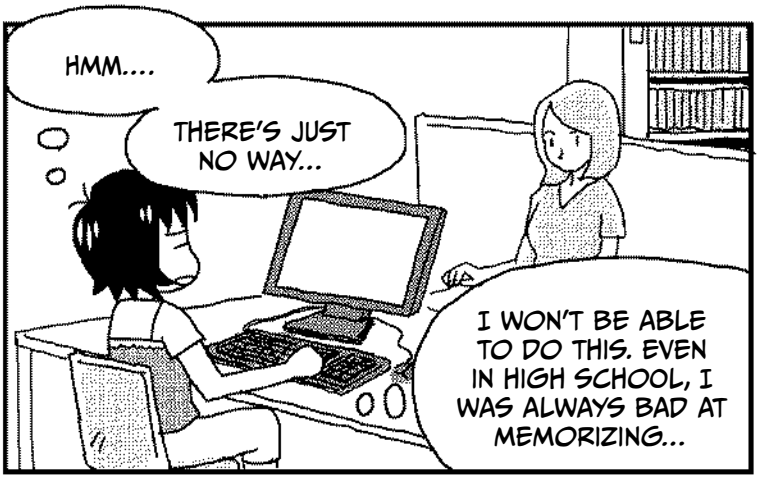
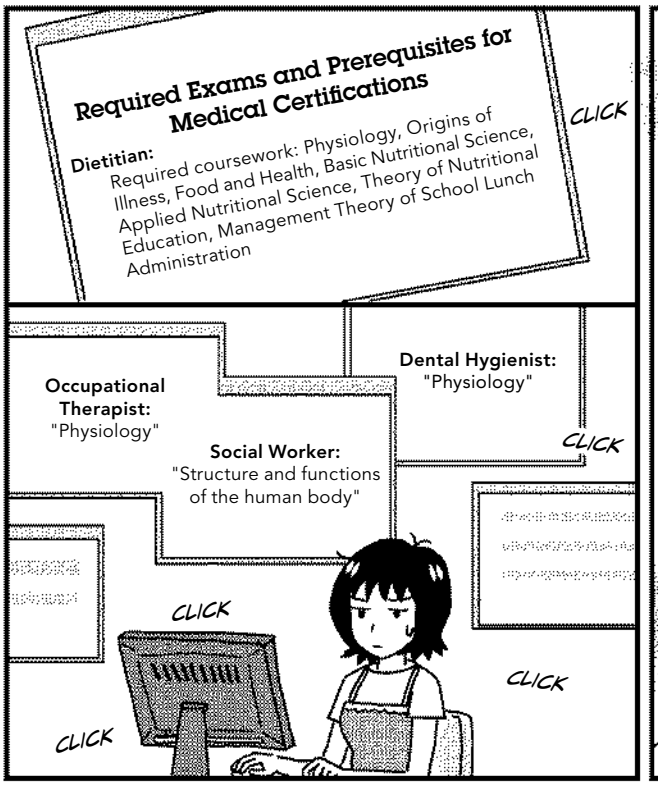
PROLOGUE

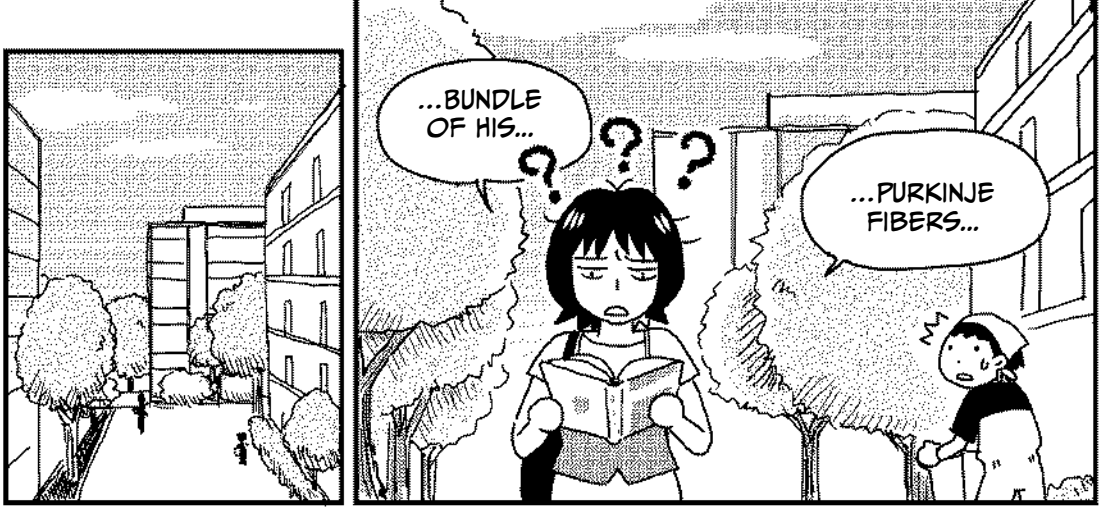
WHAT DO YOU MEAN I HAVE TO TAKE PHYSIOLOGY 101?

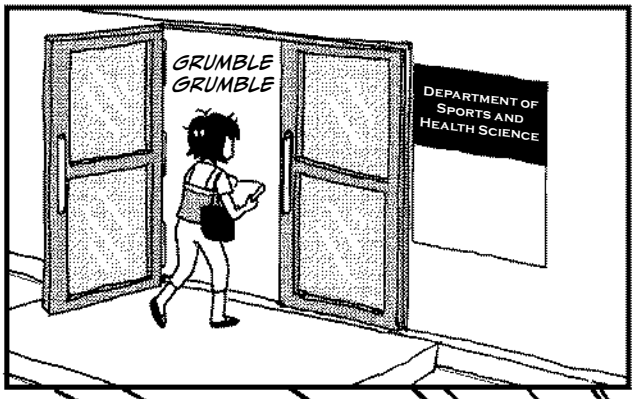


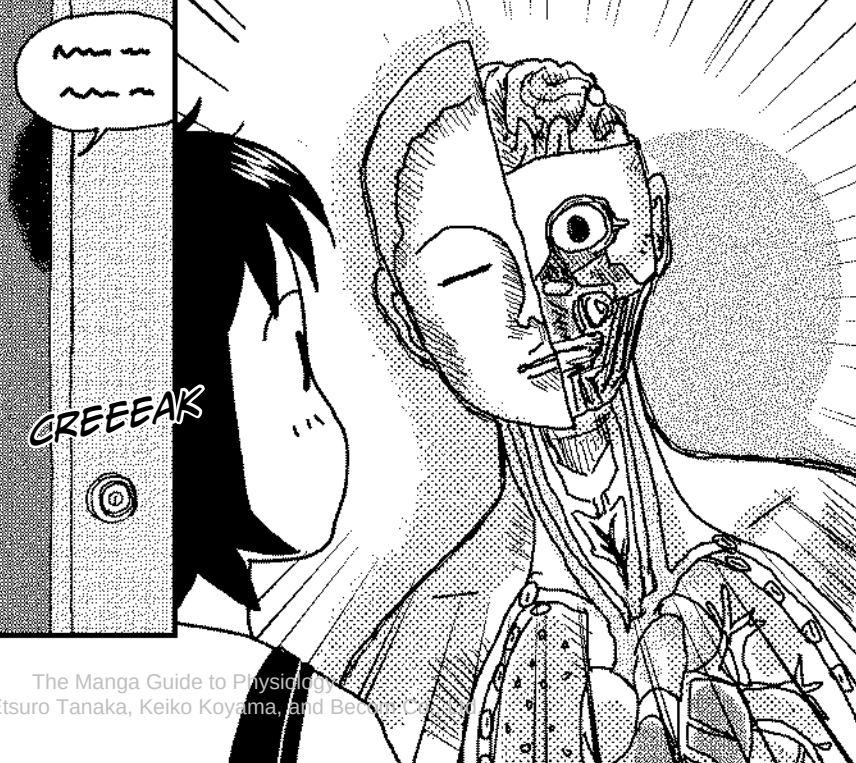








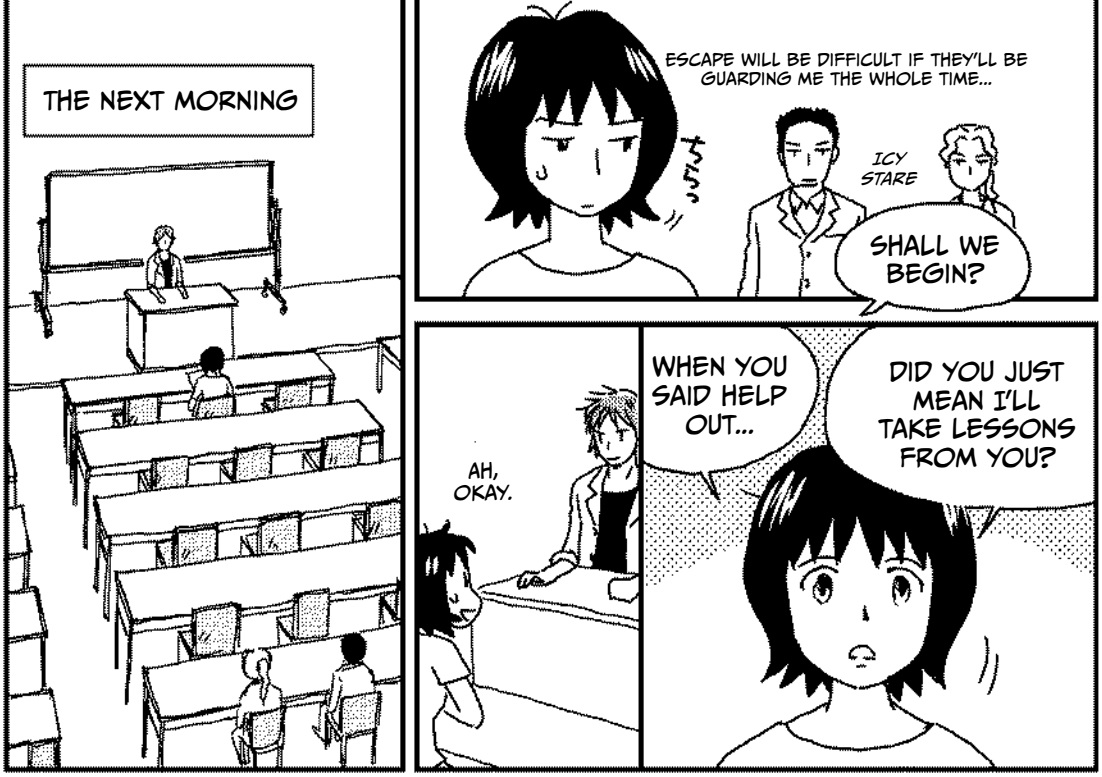


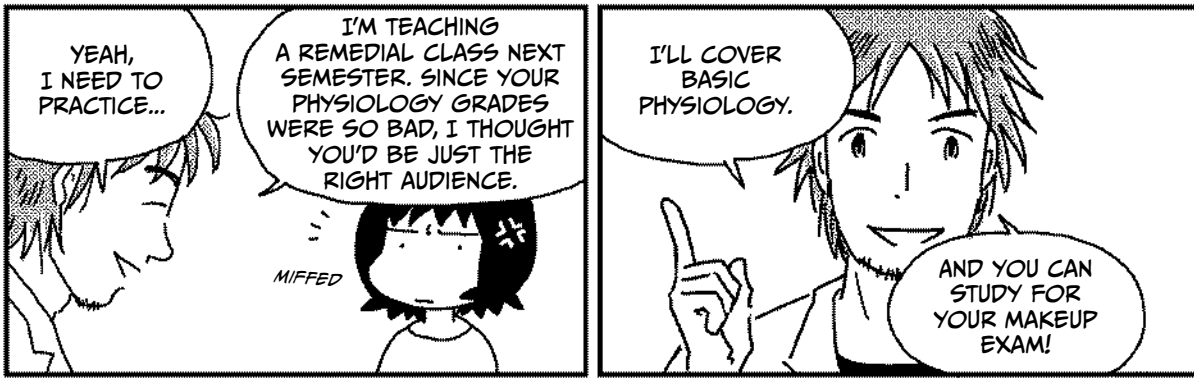


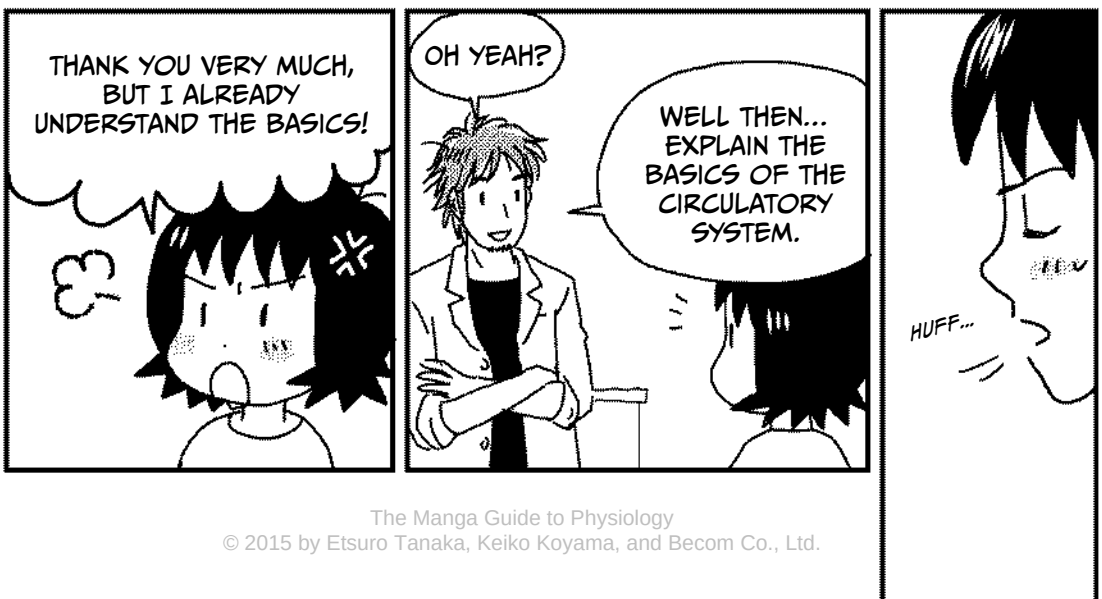
1 THE CIRCULATORY SYSTEM

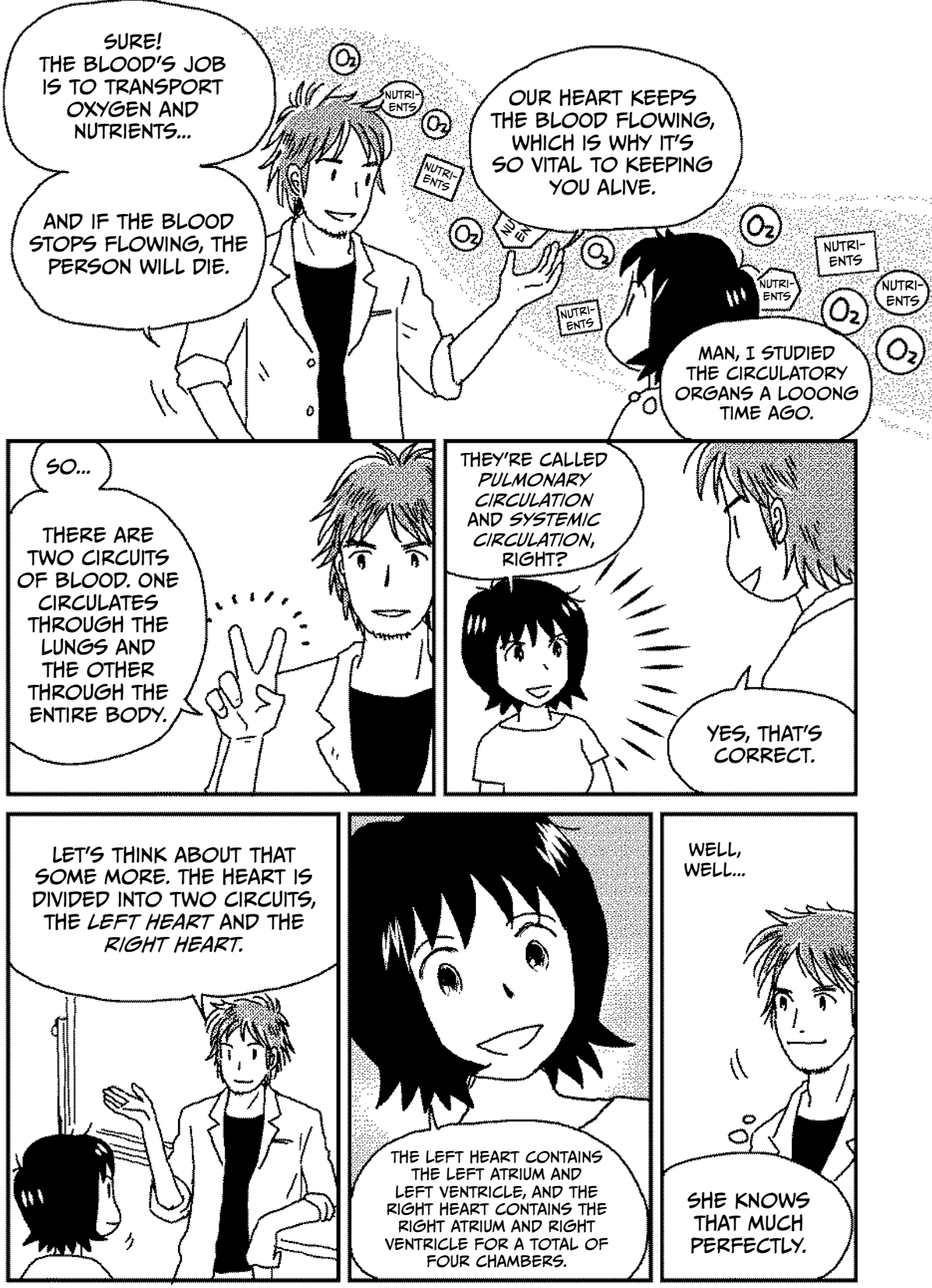
PUMPS WORKING IN HARMONY

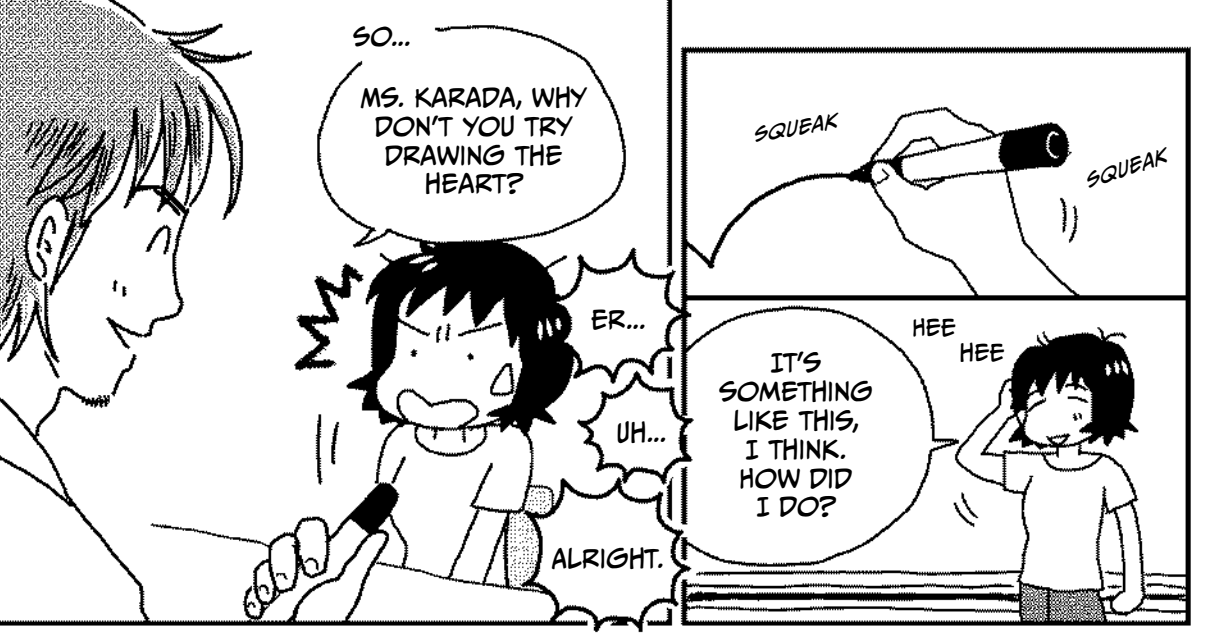
* MORE THAN ¥12,000

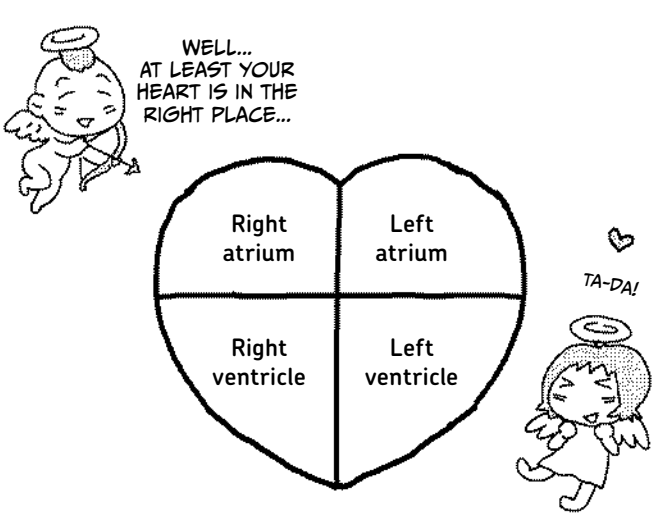


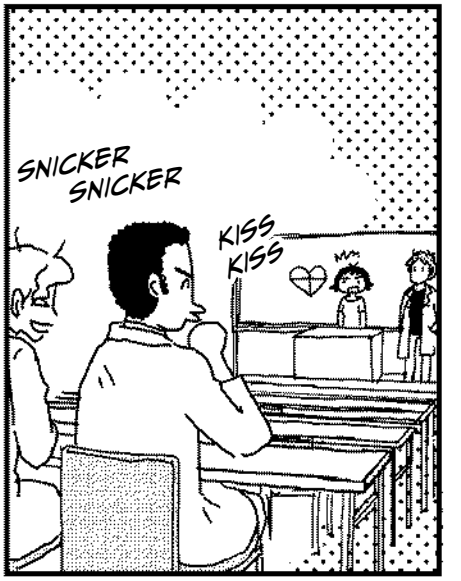


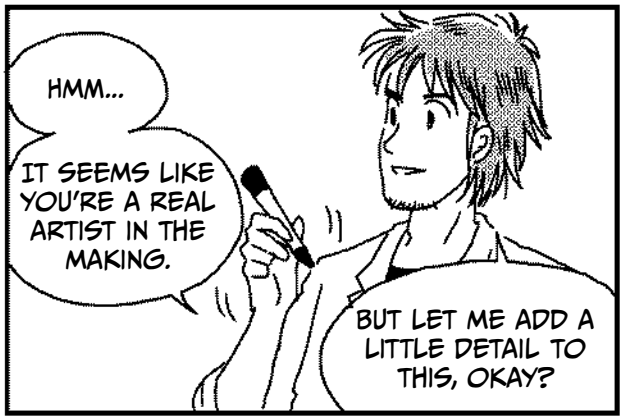






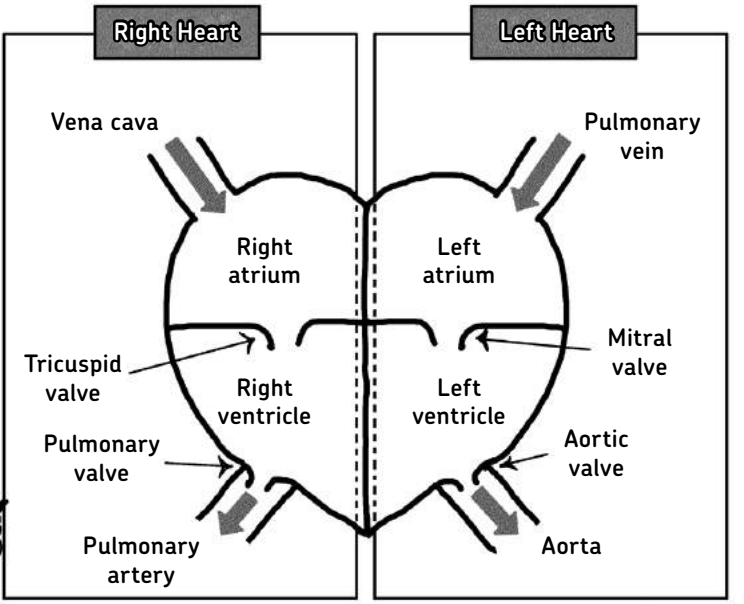




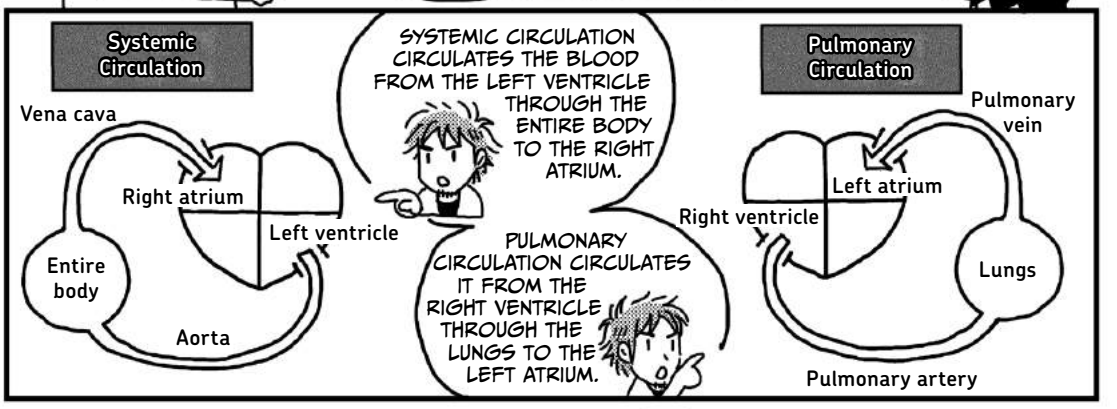


OKAY. ARTERIES AND VEINS ARE CONNECTED LIKE THIS TO THE HEART, WHICH HAS FOUR CHAMBERS AND FOUR VALVES.

THE LEFT AND RIGHT SIDES ARE ROUGHLY DIVIDED INTO THE LEFT HEART AND RIGHT HEART.



BY THE WAY, THE LEFT HEART IS THE SIDE THAT PUMPS BLOOD TO THE ENTIRE BODY.

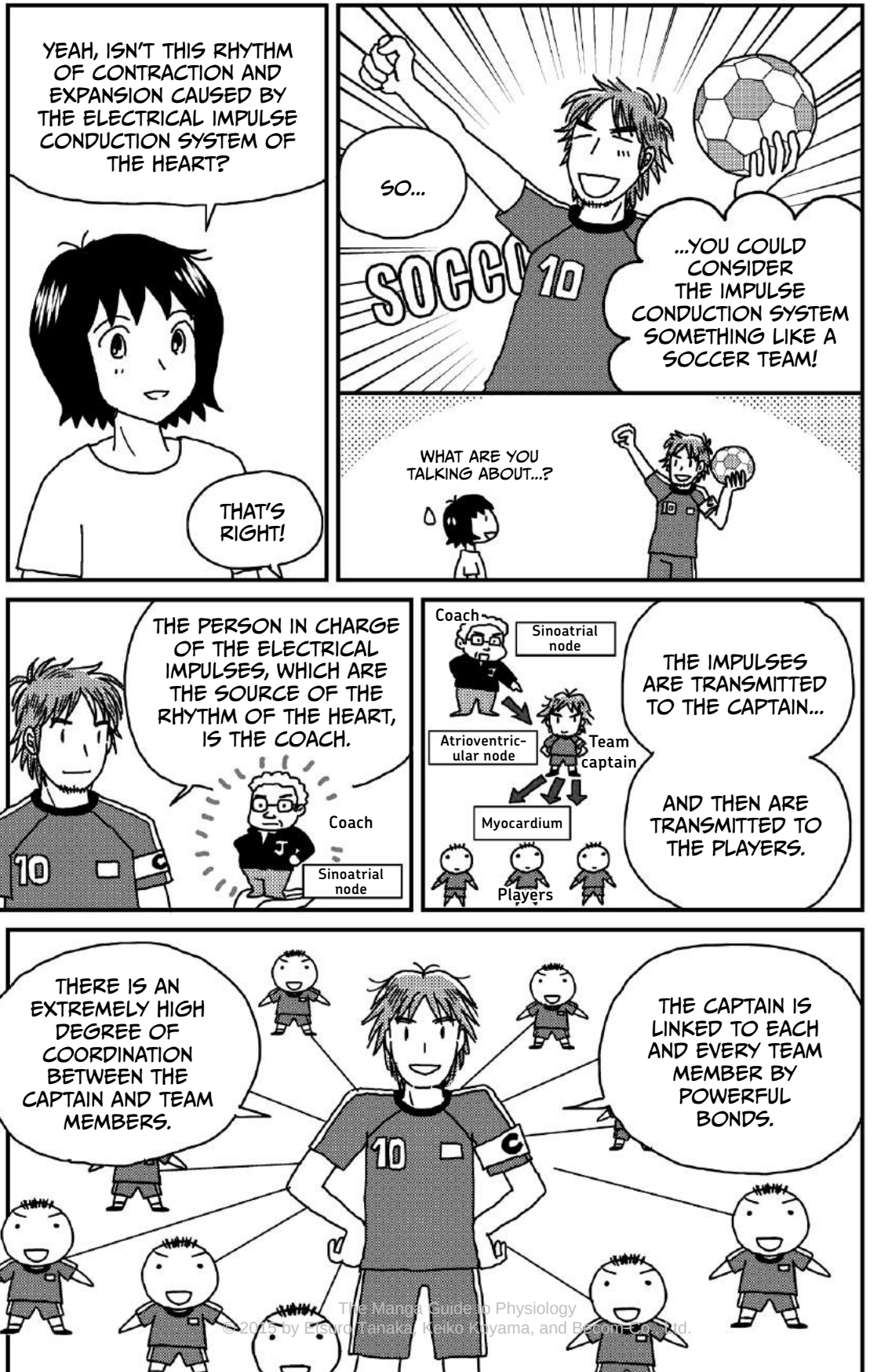


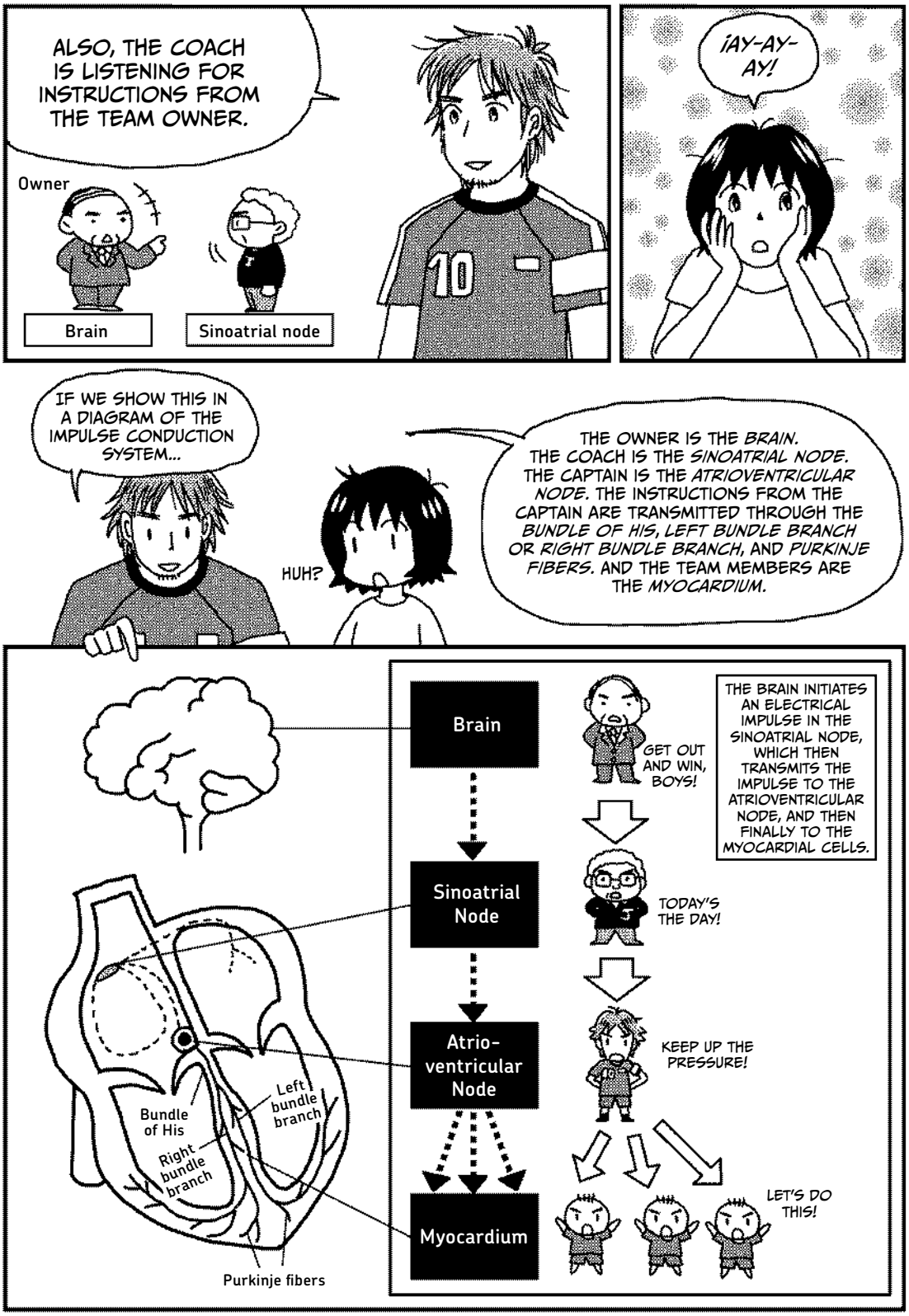
THE LEFT HEART AND RIGHT HEART ARE "PUMPS," AND SYSTEMIC CIRCULATION AND PULMONARY CIRCULATION SEND BLOOD THROUGH A SERIES OF "PIPES," RIGHT?

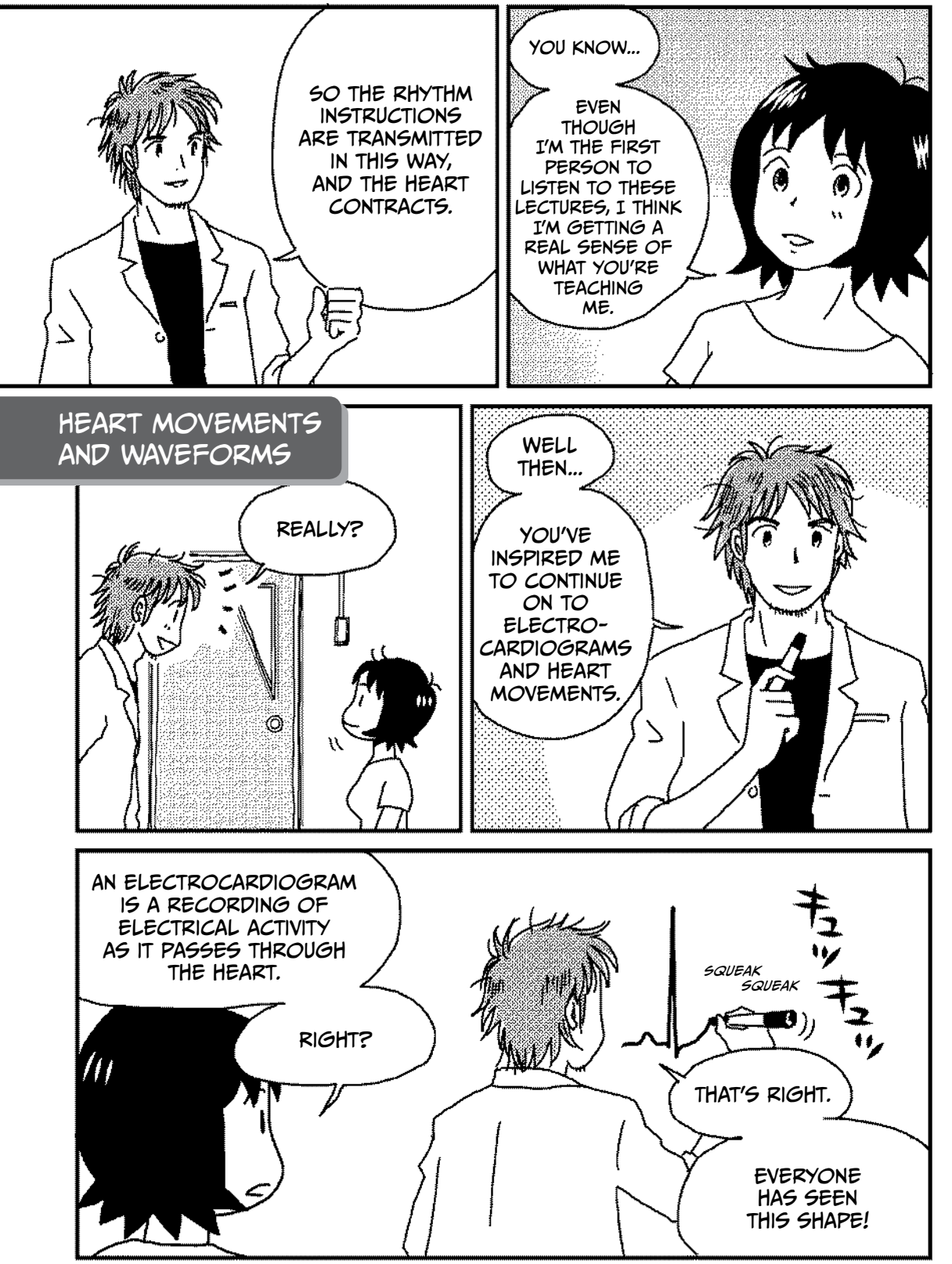
MAYBE IT'S NOT SO BASIC, AFTER ALL.

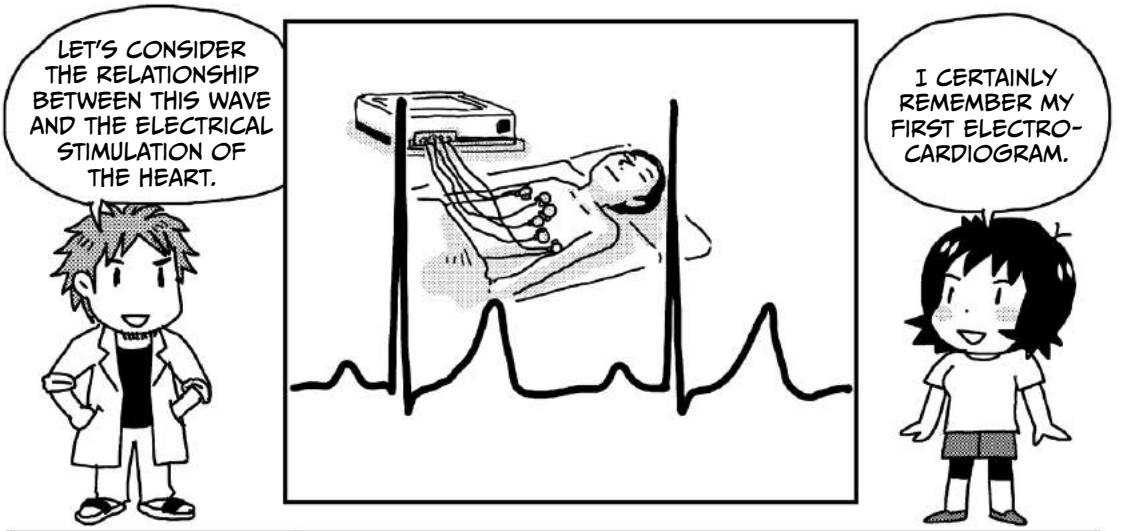
WELL, LET'S MOVE ON.

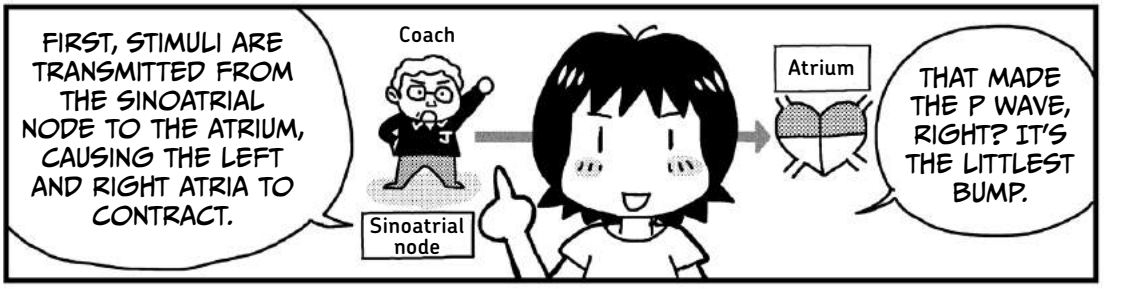
YOU KNOW THAT THE HEART CONTRACTS AND EXPANDS WITH A WELL-REGULATED RHYTHM WHEN THE MUSCLE CALLED THE *MYOCARDIUM* RECEIVES ELECTRICAL STIMULI.

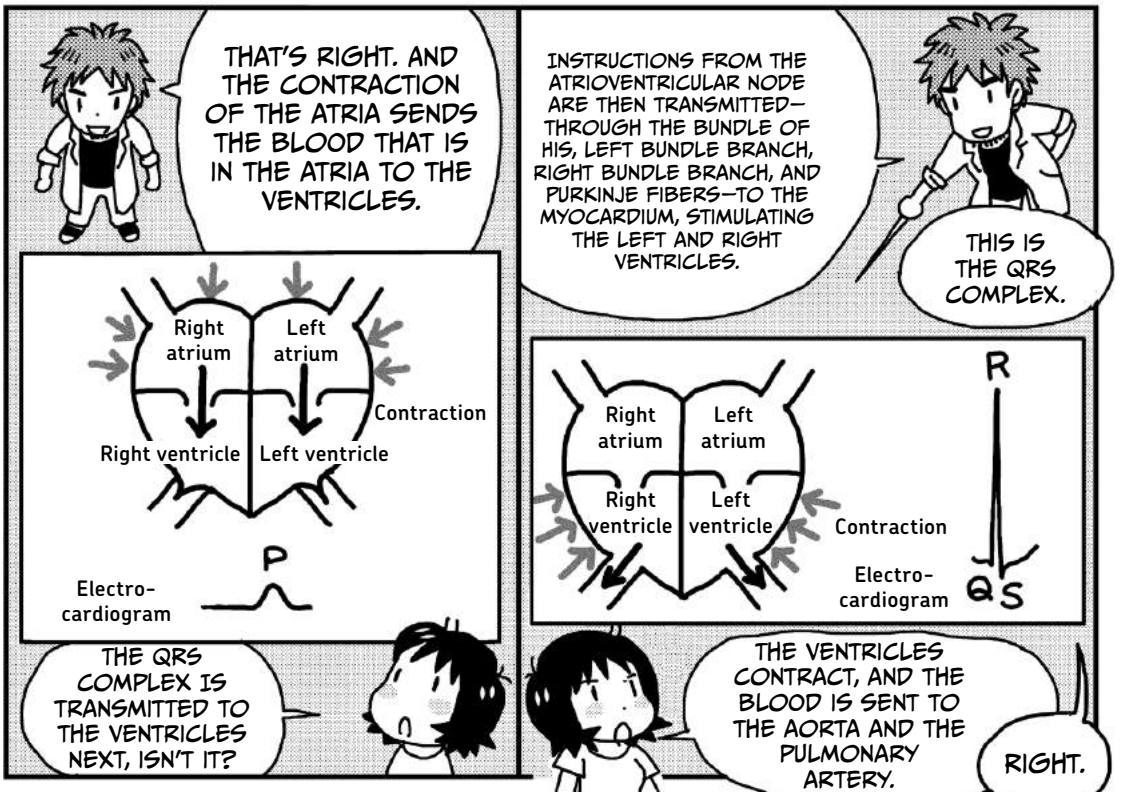


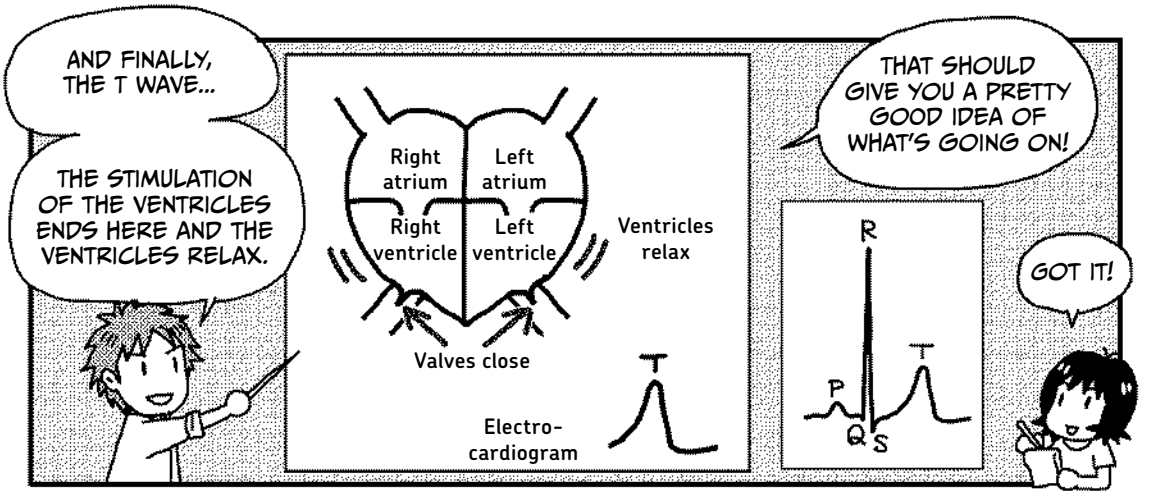


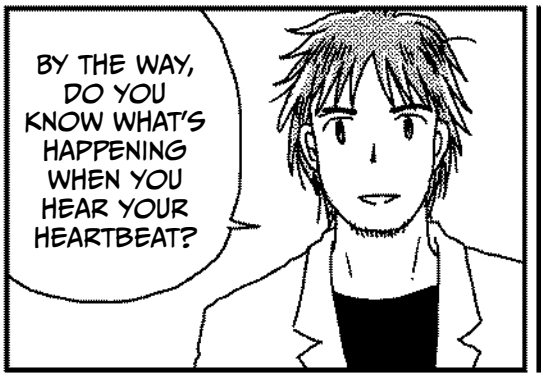


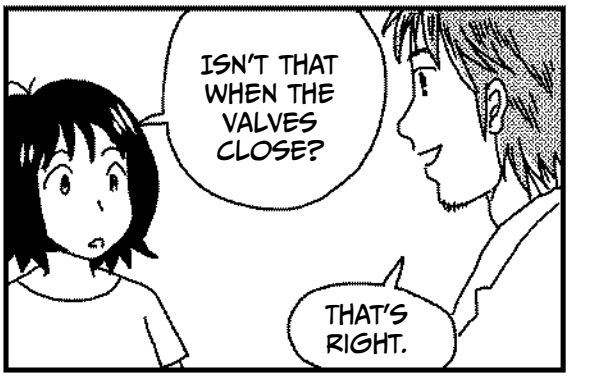


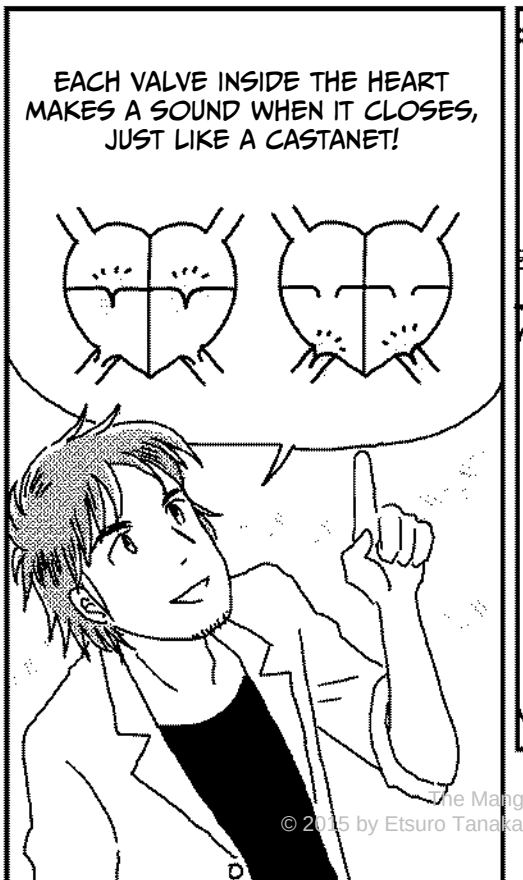


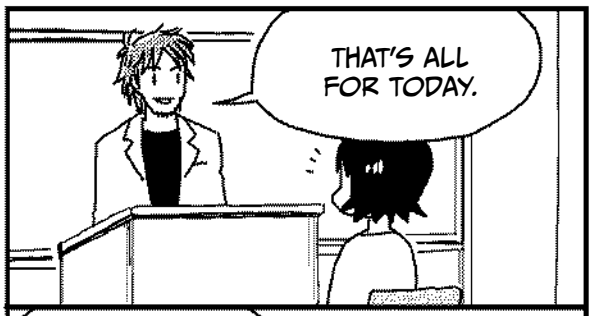


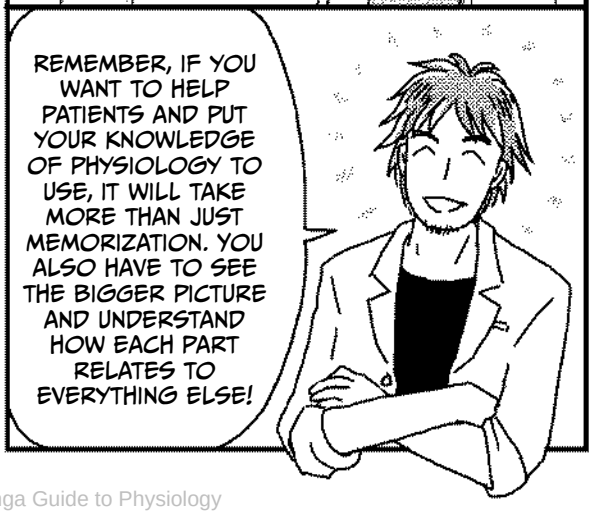


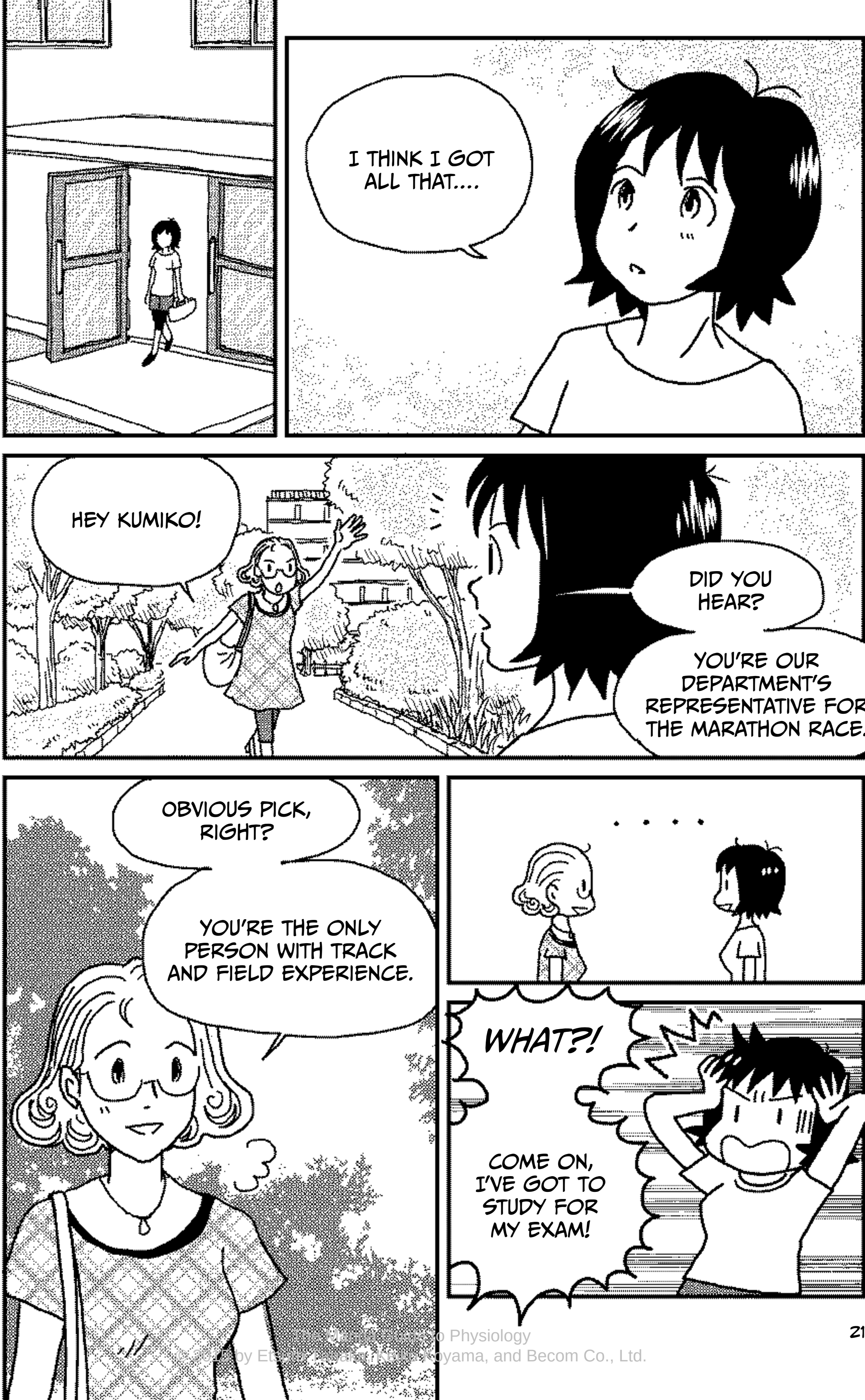












EVEN MORE ABOUT THE CIRCULATORY SYSTEM!

The circulatory system consists of the organs that circulate blood, lymph, and other fluids throughout the body. The heart, blood vessels, and lymph nodes transport oxygen, nutrients, hormones, and the like to tissues within the body while at the same time gathering waste products from various parts of the body.

Let's learn more about how the circulatory system works.

ELECTRICAL ACTIVITY IN THE HEART

The muscle that forms the walls of the heart contracts when it receives electrical stimuli. The impulse conduction system, shown in Figure 1-1, causes this contraction to occur.

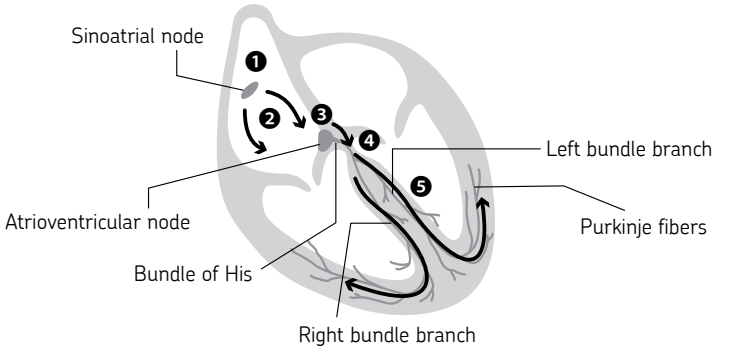


Figure 1-1: Flow of the impulse conduction system

Stimuli triggered from the *sinoatrial node* ❶ spread like waves through the entire atria, causing the atria to contract. The stimuli reach the *atrioventricular node* ❷, which is located between the left and right atria, and are transmitted to the *bundle of His* ❸. The bundle of His is divided into two branches ❹, the *left bundle branch* and *right bundle branch*. The left bundle branch and right bundle branch are further divided into numerous finer branches in the left and right ventricles, respectively. These finer branches are the *Purkinje fibers* ❺. The impulse conduction system resides in specialized muscle tissue called *cardiac muscle*, or *myocardium*.

The sinoatrial node automatically generates the stimuli, right?

That's right. It generates 60 to 80 stimuli per minute, even if it receives no instructions from the central nervous system. In other words, the sinoatrial node generates the normal heart rate and thereby acts as the heart's natural pacemaker.

Stimuli are also generated by other cardiac fibers, such as those in the atrioventricular node. However, the sinoatrial node normally controls the heart rate because it discharges stimuli faster than does any other part of the heart. If the sinoatrial node malfunctions, the

atrioventricular node becomes the pacemaker in its absence. But since the atrioventricular node generates stimuli at a slower pace, the heart rate decreases when stimulated by that node.

HOW AN ELECTROCARDIOGRAM WORKS

An electrocardiogram is a visualization of the electrical stimuli transmitted to the entire myocardium from the impulse conduction system. Normally, six electrodes are attached to the chest, and a total of four electrodes are attached to both wrists and both ankles. (Electrodes connected to both wrists and one ankle take the electrocardiogram; the right ankle is attached to a neutral, or *ground*, lead for grounding the circuit.) This lets us measure the electrocardiogram using 12 leads (see Figure 1-2).

Limb Leads	**Chest Leads**
Electrodes recording at three locations (right wrist, left wrist, and left ankle), plus one grounding lead (right ankle)	Electrodes at six locations surrounding the heart
Help doctors and nurses get a "view" of the heart in the vertical plane (a coronal plane)	Help doctors and nurses get a "view" of the heart in the horizontal plane (a transverse plane)

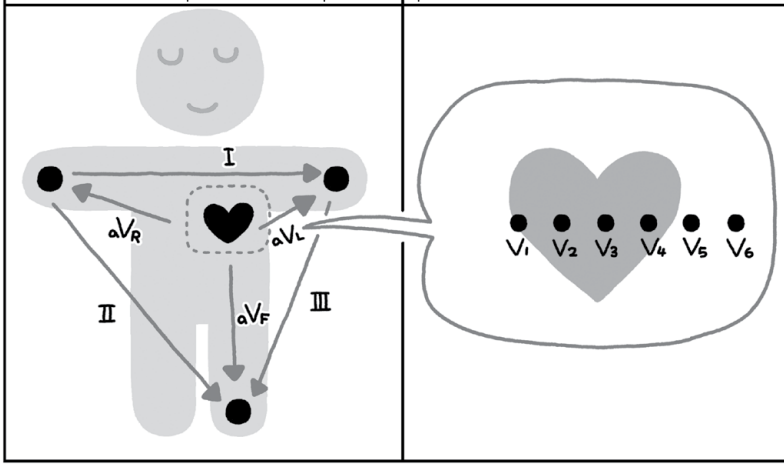


Figure 1-2: A 12-lead electrocardiogram

Why are 12 leads required? That seems like a lot.

Consider the leads to be something like cameras viewing the heart from the sites where the electrodes are attached. With that many camera angles on the scene, you've got the complete, 3D picture, and not much can be missed.

If there are well-regulated contractions of the heart, normal waveforms will appear in a continuous loop. However, if there is an abnormality in the myocardium or impulse conduction system, various changes will appear in the corresponding waveform of the electrocardiogram. For example, if there are *arrhythmias*—heart contractions with unusual timing—irregular waveforms will appear. Other types of arrhythmia are tachycardia, a heart rate that is too high, and bradycardia, one that is too low.

So approximately how much blood do you think is sent to the aorta each time the heart contracts?

Hmm . . . about a soda can's worth?

Whoa . . . wait a minute. The heart is about the size of a fist. There's no way it holds 350 milliliters. The so-called *stroke volume* of the heart is approximately 70 milliliters. That's about the size of a small bottle of perfume or pudding cup.

We can calculate the cardiac output per minute as follows:

Cardiac Output (mL/min) = Stroke Volume (mL/beat) × Heart Rate (beats/min)

DID YOU KNOW?

The heart rate of an infant is faster than that of an adult; it slows as the child ages. Most adults have a resting heart rate of about 60–80 beats per minute. An elderly person tends to have a slightly slower heart rate than a young or middle-aged adult.

Since the circulating blood volume in the human body is approximately 5 liters, all the blood circulates through the entire body in approximately 1 minute.

HOW THE NERVOUS SYSTEM AFFECTS THE CIRCULATORY SYSTEM

Your heart rate increases when you're surprised, speaking in front of an audience, playing sports, or in other stressful situations. This increase is caused by the activity of your autonomic nervous system (see page 138). If more blood flow is required due to stress or exertion, the sympathetic nervous system is excited, the sinoatrial node is stimulated, and your heart rate increases. On the other hand, when you relax, your parasympathetic nervous system reduces your heart rate.

But aren't the stimuli from the sinoatrial node automatically generated without receiving any instructions from the brain?

That's a good question! The sinoatrial node can certainly generate stimuli automatically, but the frequency of those stimuli is regulated by the *autonomic nervous system*.

The autonomic nervous system controls physiological responses ranging from blood pressure and heart rate to dilation of the pupils of the eyes. There are two branches of the autonomic nervous system: the *sympathetic branch* (which generates the "fight or flight" response) and the *parasympathetic branch* (which generates the "rest and digest" response).

The sympathetic nervous system is responsible for increasing the heart rate and causing blood vessel vasoconstriction (decreased diameter of blood vessels), both of which contribute to an increase in blood pressure. Conversely, the parasympathetic system is responsible for decreasing the heart rate, and the activation of the parasympathetic system leads to a decrease in blood pressure.

THE CORONARY ARTERIES

But before we begin talking about blood circulation, we should learn how the heart itself acquires oxygen and nutrients. Do you know which blood vessels send oxygen and nutrients to the myocardium?

The coronary arteries?

That's right. The *coronary arteries* are called that because they encircle the heart in a crown shape. Just think about a coronation ceremony for a new queen, where she gets her crown.

The coronary arteries are roughly divided into the right coronary artery and left coronary artery (Figure 1-3). The smaller branches of the coronary arteries penetrate the surface of the cardiac muscle mass and thus serve as the primary sources of oxygen and nutrients for the myocardium.

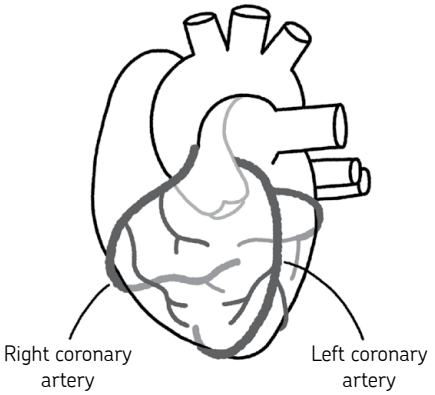


Figure 1-3: The coronary arteries

You'd think the heart would be able to get all the oxygen and nutrients it needs from the blood it is constantly pumping through its chambers. But actually, it can absorb only a minuscule amount of oxygen and nutrients that way, so the coronary arteries are needed to deliver blood deep into the muscle tissue of the heart.

The arteries of most internal organs branch and reconnect (*anastomose*). Therefore, even if a blood vessel is blocked at one location, the blood will flow along another route. However, the coronary arteries surrounding the heart are called end arteries since they are structured with no anastomoses between arterial branches (Figure 1-4). Therefore, if there is a blockage somewhere, blood will cease flowing beyond that point, causing a heart attack.

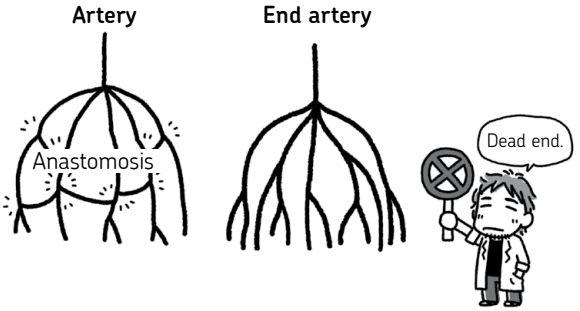


Figure 1-4: End arteries branch with no points of anastomosis.

DID YOU KNOW?

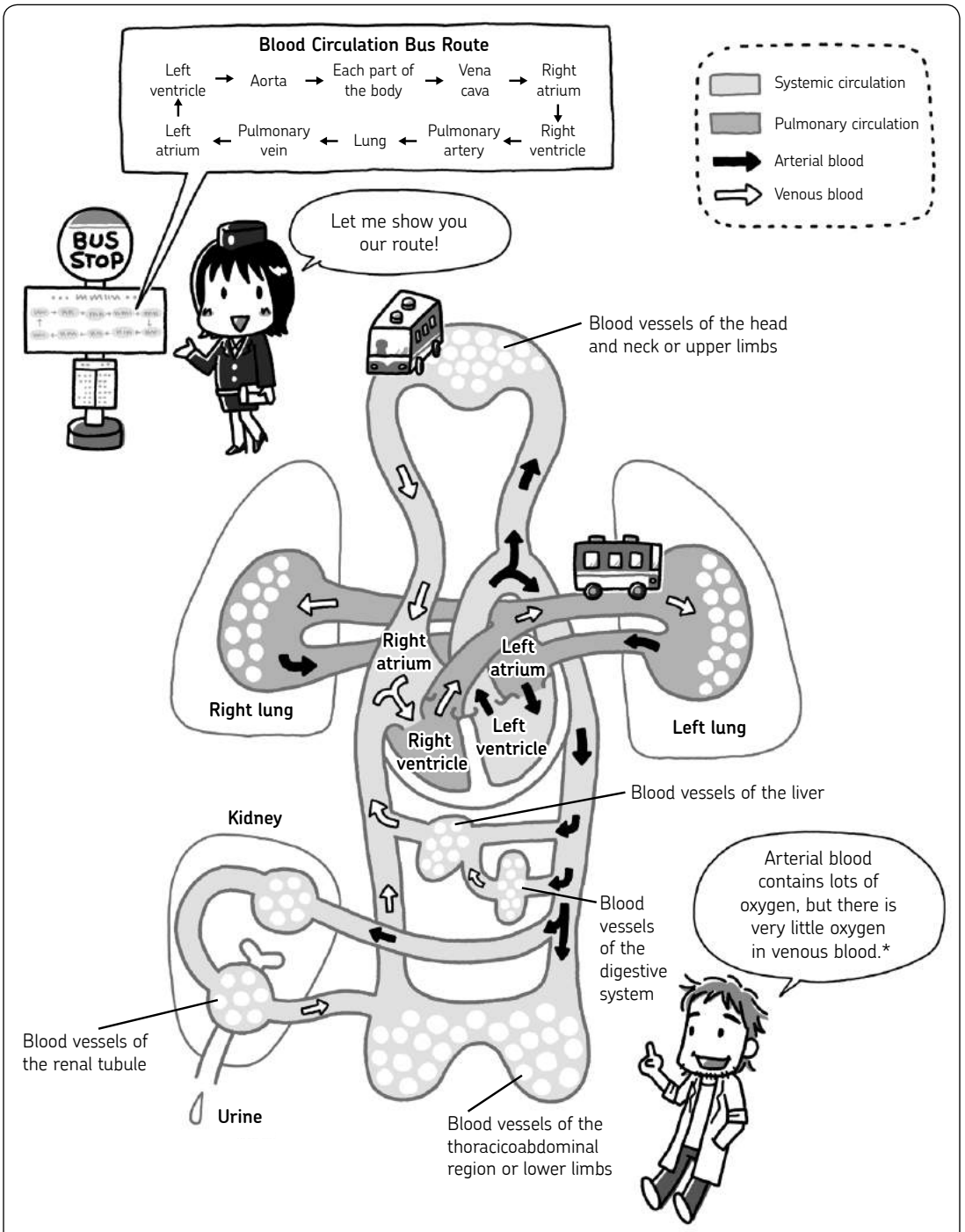
The coronary arteries aren't the only end arteries. Others are found in the brain. A blockage (or vascular occlusion) in these end arteries in the brain is very serious. A complete blockage will cause a stroke.

BLOOD CIRCULATION

We learned that there are two circuits for blood circulation: pulmonary circulation and systemic circulation. Do you think you can explain them properly?

Pulmonary circulation circulates from the right ventricle and through the lungs to capture oxygen before returning to the left atrium, and *systemic circulation* circulates from the left ventricle and through the entire body to send oxygen and nutrients to the body before returning to the right atrium.

That's exactly right! The pulmonary circulation and systemic circulation flows are depicted in a rough diagram in Figure 1-5. Since this is basic information needed for studying each of the internal organs later, make sure you understand this entire drawing.



* Generally, arterial (oxygenated) blood flows in arteries, and venous (low in oxygen) blood flows in veins. There are some exceptions of course. Deoxygenated blood flows in the pulmonary artery from the heart to the lungs, and the pulmonary veins carry oxygenated blood from the lungs back to the heart.

Figure 1-5: Blood circulation

We ought to also touch on arteries and veins here. Remember that *arteries* are blood vessels carrying blood away from the heart and *veins* are blood vessels returning blood to the heart via the capillaries.

Because arteries receive blood that is pushed out of the heart under great pressure, the blood vessel walls are thick, and their elasticity and internal pressure are both high. Veins have thin blood vessel walls with valves at various locations to prevent blood from flowing backward. The internal pressure is low, and blood flow is assisted by surrounding muscles. Some veins run just below the skin. These are called superficial veins. Blood is often drawn from the median cubital vein on the inside of the elbow. This is also a superficial vein.

Although arteries often run deep within the body, they also pass through places where it is easy to take a pulse (see Figure 1-6).

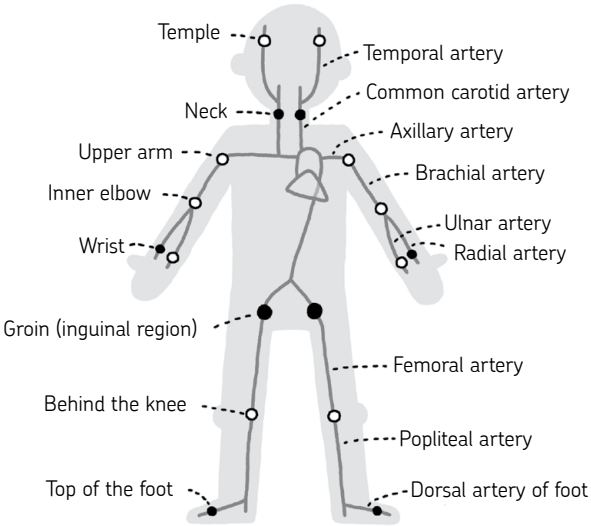


Figure 1-6: Locations for taking a pulse

These are arteries that run through locations that are relatively shallow, such as the wrist, aren't they?

That's right. In a medical clinic, your pulse is often taken using the radial artery of your wrist or the carotid artery of your neck.

BLOOD PRESSURE

Blood pressure is the internal pressure inside blood vessels, but the term is usually used to mean the pressure in large arteries near the heart, such as in the upper arm. What are some factors that determine blood pressure?

Factors? Well, er, age and diet and . . .

Yes, blood pressure certainly tends to increase as a person becomes middle aged and older, but let's consider physiological factors here.

Three factors that determine blood pressure are the girth of the blood vessels, the circulating blood volume, and the contractile force of the heart, or cardiac contractile force (see Figure 1-7). For example, if the circulating blood volume (the total volume of blood in the arteries) and the cardiac contractile force are fixed, then blood pressure will increase if the blood vessels are smaller. Also, the blood pressure will drop if the blood volume decreases because of a hemorrhage or if the contractile pressure of the heart decreases because of a heart attack.

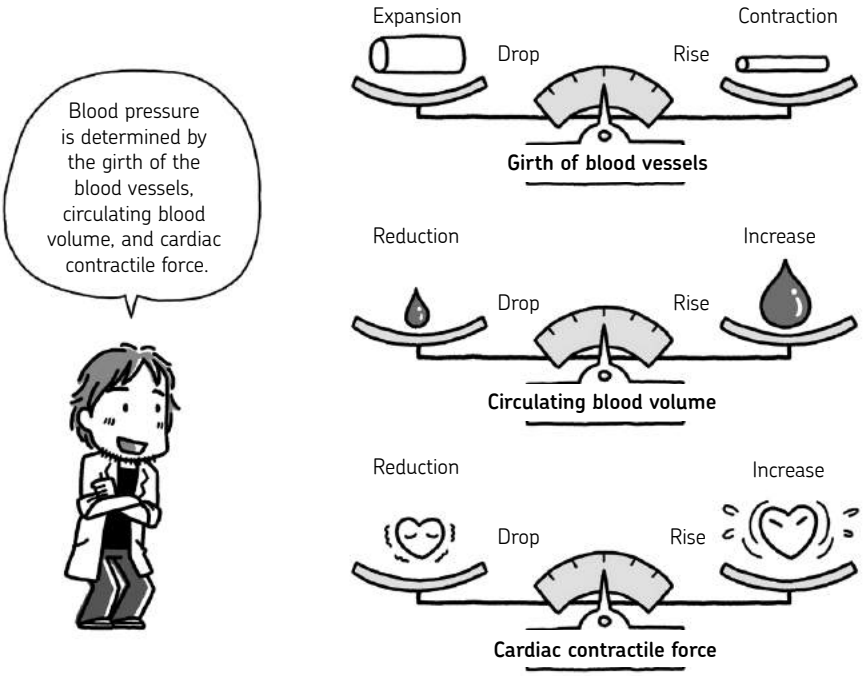


Figure 1-7: Factors that determine blood pressure

MEASURING BLOOD PRESSURE

You've studied the principles and techniques of blood pressure measurement, haven't you?

Sure, I did that in basic nursing.

Blood pressure varies like a wave, getting higher when the ventricles contract and lower when they relax. The maximum pressure is called the *systolic pressure*, and the minimum is called the *diastolic pressure*.

You inflate the cuff that's wrapped around the upper arm to restrict the blood flow. Then you release the air in the cuff a little at a time while you listen to the artery through a stethoscope. When you start to hear a tapping sound (called Korotkoff sounds), that is the systolic pressure. You continue to release air, and when you no longer can hear any sound, that is the diastolic pressure. The cuff's pressure readings at these two points give you the patient's blood pressure (see Figure 1-8).

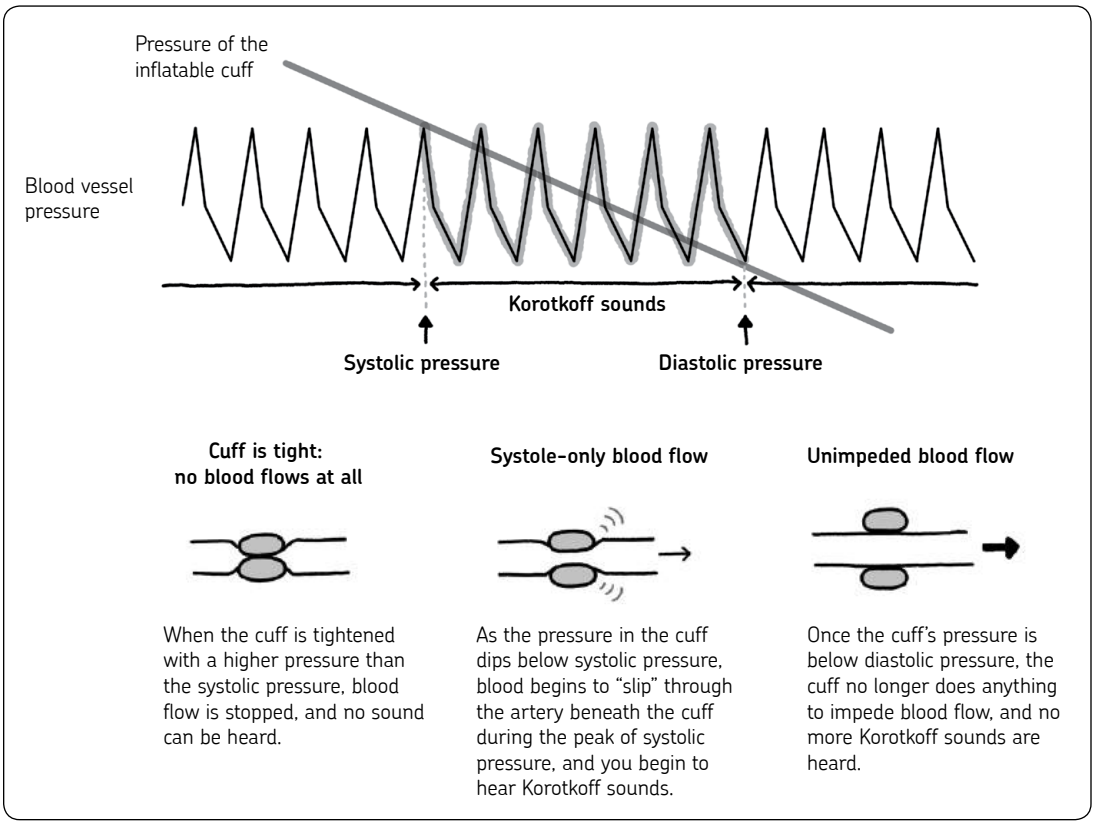


Figure 1-8: Blood pressure measurement by the auscultatory method

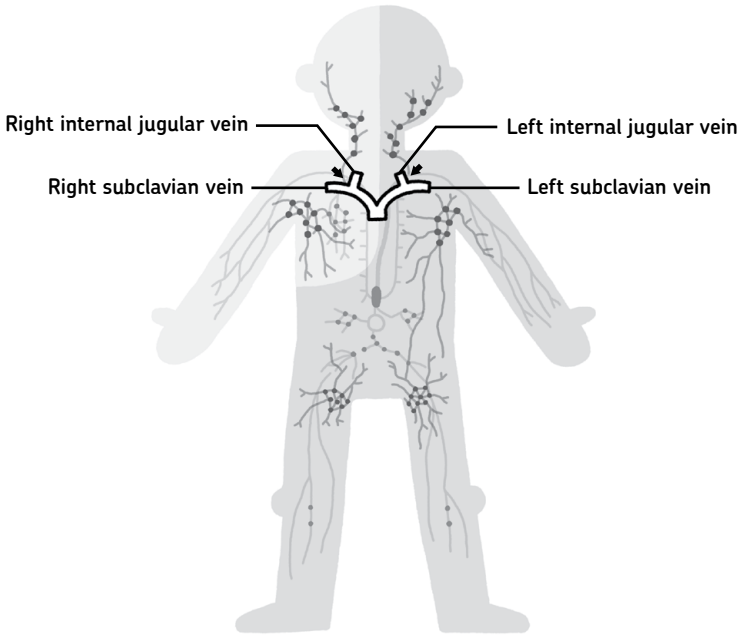
DID YOU KNOW?

Blood pressure units are represented by mm Hg (millimeters of mercury). The number of mm Hg indicates the number of millimeters that mercury would be pressed upward in a tube by the pressure.

THE LYMPHATIC SYSTEM

The last part of the circulatory system is the *lymphatic system*, which recovers bodily fluids that seep into tissues from capillaries and returns them to the heart. It also supports the immune system. In this way, the lymphatic organs can be said to reside in both the circulatory system and the immune system. In peripheral tissue, interstitial fluid is exchanged between capillaries and tissue, but some of the interstitial fluid is collected in the lymphatic vessels. The bodily fluid in the lymphatic vessels is called *lymph*. The lymph flow rate is approximately 2 to 3 liters per day.

The lymphatic vessels start from lymphatic capillaries, which gradually come together to form larger lymph vessels. After passing through many lymph nodes along the way, they finally enter the left and right venous angles, which are confluence points of the subclavian veins and internal jugular veins (see Figure 1-9). Valves are attached to the interior of the lymphatic vessels to prevent the lymph flow from reversing direction.



Lymph reenters the circulatory system where the arrows point, near the junction between the jugular vein and subclavian vein.

Figure 1-9: The lymphatic system

The lymphatic vessels are not symmetrical on the left and right sides of the body.

Good eye! Notice the light and dark shading in Figure 1-9. The right lymphatic trunk, in which the lymphatic vessels from the upper right half of the body are collected together, enters into the right venous angle. The collected lymphatic vessels from the remaining upper left half of the body and the entire lower half of the body enter into the left venous angle.

DID YOU KNOW?

Cancer that starts in the lymph nodes is called lymphoma. More often, cancer starts somewhere else and then spreads to lymph nodes. When cancer spreads or metastasizes, it often is found in the lymph nodes.