

Chapter 10

Spreading the Love: The Circulatory System

In This Chapter

- ▶ Understanding the heart's rhythm and structure
 - ▶ Identifying the heart's chambers and valves
 - ▶ Tracing arteries, veins, and capillaries
 - ▶ Touching on fetal circulation
-

This chapter gets to the heart of the well-oiled human machine to see how its central pump is the hardest-working muscle in the entire body. From a month after you're conceived to the moment of your death, this phenomenal powerhouse pushes a liquid connective tissue — blood — and its precious cargo of oxygen and nutrients to every nook and cranny of the body, and then it keeps things moving to bring carbon dioxide and waste products back out again. In the first seven decades of human life, the heart beats roughly 2.5 billion times. Do the math: How many pulses has your ticker clocked if the average heart keeps up a pace of 72 beats per minute, 100,000 per day, or roughly 36 million per year?

Moving to the Beat of a Pump

Also called the *cardiovascular system*, the circulatory system includes the heart, all blood vessels, and the blood that moves endlessly through it all (see Figure 10-1). It's what's referred to as a *closed double system*; the term "closed" is used for three reasons: because the blood is contained in the heart and its vessels; because the vessels specifically target the blood to the tissues; and because the heart critically regulates blood flow to the tissues. The system is called "double" because there are two distinct circuits and cavities within the heart separated by a wall of muscle called the *septum*. (Each cavity in turn has two chambers called *atria* on top and *ventricles* below). The double circuits are the following:

- ✓ The *pulmonary circuit* carries blood to and from the lungs for gaseous exchange. Centered in the right side of the heart, this circuit receives blood saturated with carbon dioxide from the veins and pumps it through the *pulmonary artery* (or *trunk*) to capillaries in the lungs, where the carbon dioxide departs the system. That same blood, freshly loaded with oxygen, then returns to the left side of the heart through the *pulmonary veins* where it enters the second circuit.
- ✓ The *systemic circuit* uses the oxygen-rich blood to maintain a constant internal environment around the body's tissues. From the left side of the heart, the blood moves through the *aorta* to a variety of systemic arteries for distribution throughout the body.

After oxygen is exchanged for carbon dioxide, the blood returns to the pulmonary circuit on the right side of the heart via the *superior* and *inferior venae cavae* (the singular is *vena cava*).

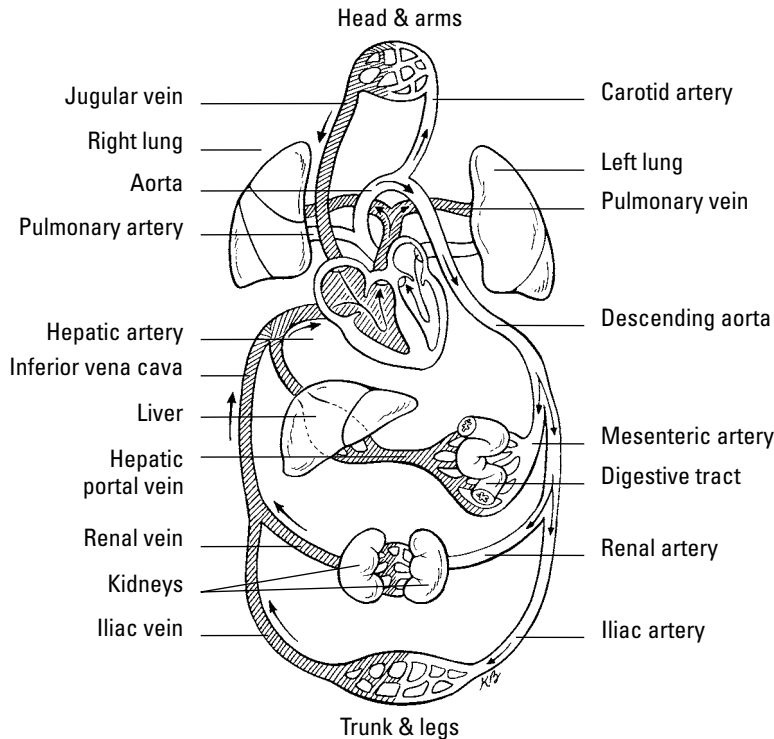


Figure 10-1: The circulatory system is a closed double system.

Although cutely depicted in popular culture as uniformly curvaceous, the heart actually looks more like a blunt, muscular cone (roughly the size of a fist) resting on the diaphragm. A fluid-filled, fibrous sac called the *pericardium* (or *heart sac*) wraps loosely around the package; it's attached to the large blood vessels emerging from the heart but not to the heart itself. The sternum (breastbone) and third to sixth costal cartilages of the ribs provide protection in front of (ventrally to) the heart. Behind it lie the fifth to eighth thoracic vertebrae. Two-thirds of the heart lies to the left of the body's center, with its *apex* (cone) pointed down and to the left. At less than 5 inches long and a bit more than 3 inches wide, an adult human heart weighs around 10 ounces — a couple ounces shy of a can of soda.

Three layers make up the wall of the heart.

- ✓ On the outside lies the *epicardium* (or *visceral pericardium*), which is composed of fibroelastic connective tissue dappled with adipose tissue (fat) that fills external grooves called *sulci* (the singular is *sulcus*). The larger coronary vessels and nerves are found in the adipose tissue that fills the sulci.
- ✓ Beneath the epicardium lies the *myocardium*, which is composed of layers and bundles of cardiac muscle tissue.
- ✓ The *endocardium*, the heart's interior lining, is composed of simple squamous endothelial cells.



Too much to remember? To keep the layers straight, turn to the Greek roots. *Epi-* is the Greek term for “upon” or “on” whereas *endo-* comes from the Greek *endon* meaning “within.” The medical definition of *myo-* is “muscle.” And *peri-* comes from the Greek term for “around” or “surround.” Hence the *epicardium* is *on* the heart, the *endocardium* is *inside* the heart, the *myocardium* is the *muscle* between the two, and the *pericardium* surrounds the whole package. By the way, the root *cardi-* comes from the Greek word for heart, *kardia*.

The pericardium is made up of two parts — a tough inelastic sac called the *fibrous pericardium* on the outside and a serous (or lubricated) membrane nearer the heart called the *parietal pericardium*. Between the serous layers of the *epicardium* and the parietal pericardium is the small *pericardial space* and its tiny amount of lubricating *pericardial fluid*. This watery substance prevents irritation during *systole* (contraction of the heart) and *diastole* (relaxation of the heart).

Give these practice questions a try to see if you have the rhythm of all this:

- 1.-5. Match the description to its anatomical term.

1. ____ The system for gaseous exchange in the lungs	a. Pericardium
2. ____ The system for maintaining a constant internal environment in other tissues	b. Pulmonary circuit
3. ____ The membranous sac that surrounds the heart	c. Systemic circuit
4. ____ The wall that divides the heart into two cavities	d. Atria
5. ____ Uppermost two chambers of the heart	e. Septum
6. The heart contracts at an average rate of
 - a. 110 times/minute
 - b. 72 times/minute
 - c. 12 times/minute
 - d. 42 times/minute
 - e. 24 times/minute
7. A closed system of circulation involves
 - a. Non-confinement of blood, general dispersal, minimal regulation
 - b. Confinement of blood, general dispersal, critical regulation
 - c. Non-confinement of blood, specific targeting, critical regulation
 - d. Confinement of blood, specific targeting, critical regulation
 - e. Confinement of blood, specific targeting, minimal regulation
8. The inner layer of the heart’s wall is called the
 - a. Pericardium
 - b. Epicardium
 - c. Endocardium
 - d. Endothelium

9.–13. Match the description to its anatomical term.

- | | |
|---|-------------------------|
| 9. ____ A membranous, serous layer attached to a fibrous sac | a. Visceral pericardium |
| 10. ____ A tissue composed of layers and bundles of cardiac muscles | b. Sulci |
| 11. ____ Outside layer of the heart wall that's interspersed with adipose | c. Endocardium |
| 12. ____ The interior lining of the heart | d. Myocardium |
| 13. ____ External grooves that indicate the regions of the heart | e. Parietal pericardium |

Finding the Key to the Heart's Chambers

The heart's lower two chambers, the ventricles, are quite a bit larger than the two atria up top. Yet the proper anatomical terms for their positions refer to the atria as being “superior” (above) and the ventricles “inferior” (below). In this case, size isn't the issue at all.

The atria

Sometimes referred to as “receiving chambers” because they receive blood returning to the heart through the veins, each atrium has two parts: a *principal cavity* with a smooth interior surface and an *auricle*, a smaller, dog-ear-shaped pouch with muscular ridges inside called *pectinate muscles*, or *musculi pectinati*, that resemble the teeth of a comb.

The right atrium appears slightly larger than the left and has somewhat thinner walls than the left. Its principal cavity, the *sinus venarum cavarum*, is between the two *vena cavae* and the *atrioventricular* (between an atrium and a ventricle) openings. The point where the right atrium's auricle joins with its principal cavity is marked externally by the *sulcus terminalis* and internally by the *crista terminalis*. Openings into the right atrium include the following:

- ✓ The *superior vena cava*, which has no valve and returns blood from the head, thorax, and upper extremities and directs it toward the atrioventricular opening
- ✓ The *inferior vena cava*, which returns blood from the trunk and lower extremities and directs it toward the *fossa ovalis* in the interatrial septum, which also has no valve
- ✓ The *coronary sinus*, which opens between the inferior vena cava and the atrioventricular opening, returns blood from the heart, and is covered by the ineffective *Thebesian valve*
- ✓ An atrioventricular opening covered by the *tricuspid valve*

- ✓ The *fossa ovalis* is an oval depression in the interatrial septum that corresponds to the foramen ovale of the fetal heart. If the foramen ovale does not close at birth, it causes a condition known as “blue baby.”

The left atrium’s principal cavity contains openings for the four *pulmonary veins*, two from each lung, which have no valves. Frequently, the two left veins share a common opening. The left auricle, a dog-ear-shaped blind pouch, is longer, narrower, and more curved than the right, marked interiorly by the pectinate muscles, and the left atrium’s atrioventricular (or AV) opening is smaller than on the right and is protected by the *mitral*, or *bicuspid*, valve.

The ventricles

The heart’s ventricles are sometimes called the pumping chambers because it’s their job to receive blood from the atria and pump it back to the lungs and out into the body’s network of arteries. More force is needed to move the blood great distances, so the myocardium of the ventricles is thicker than that of either atrium, and the myocardium of the left ventricle is thicker than that of the right.

The right ventricle only has to move blood to the lungs, so its myocardium is only one-third as thick as that of its neighbor to the left. Roughly triangular in shape, the right ventricle occupies much of the *sternocostal* (front) surface of the heart and forms the *conus arteriosus* where it joins the *pulmonary artery*, or *trunk*. The right ventricle extends downward toward where the heart rests against the diaphragm. A circular opening into the pulmonary trunk is covered by the *pulmonary semilunar valve*, so-called because of its three crescent-shaped cusps. When the ventricle relaxes, the blood from the pulmonary artery tends to flow back toward the ventricle, filling the pockets of the cusps and causing the valve to close. The oval AV opening is surrounded by a strong fibrous ring and covered by the *tricuspid valve*, named after its three unequal sized cusps. The atrial surface of the tricuspid valve is smooth, but the side toward the ventricle is irregular, forming a ragged edge where the *chordae tendineae* attach. These fibrous cords, which are attached to nipple-shaped projections called *papillary muscles* in the ventricle’s wall, prevent blood from flowing back into the atrium. Cardiac muscle in the ventricle’s wall is in an irregular pattern of bundles and bands called the *trabeculae carneae*.

Longer and more conical in shape, the left ventricle’s tip forms the apex of the heart. Its walls are three times thicker than those of the right ventricle. Its AV opening is smaller than that in the right ventricle and is covered by the *bicuspid*, or *mitral*, valve that’s comprised of two unequal cusps. This ventricle’s chordae tendineae are fewer, thicker, and stronger, and they’re attached by only two larger papillary muscles, one on the front (anterior) wall and one on the back (posterior). More ridges are packed more densely in the muscular trabeculae carneae. Its opening to the aorta is protected by the *aortic semilunar valve*, composed of three half-moon cusps that are larger, thicker, and stronger than the pulmonary valve’s cusps. Between these cusps and the aortic wall are dilated pockets called *aortic sinuses*, which are openings for the *coronary arteries*.

Pump up your practice time with these questions related to the chambers of the heart:

14.-29. Use the terms that follow to identify the heart's major vessels shown in Figure 10-2.

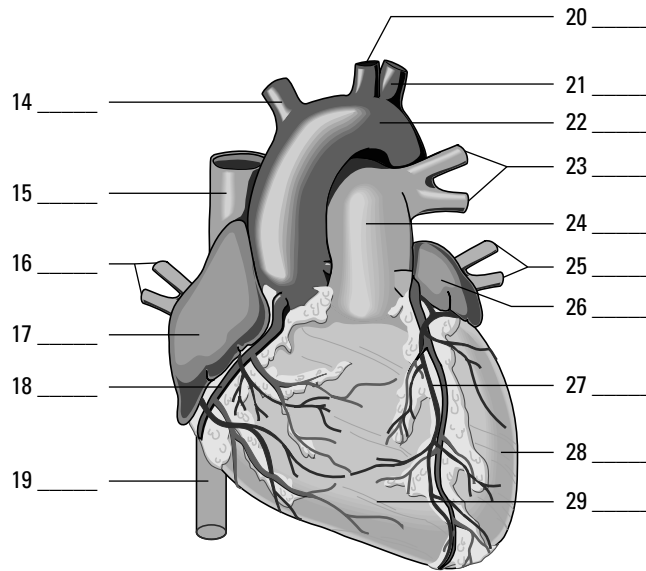


Figure 10-2:
The heart
and major
vessels.

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- a. Left pulmonary veins
- b. Left ventricle
- c. Brachiocephalic trunk
- d. Right pulmonary veins
- e. Right ventricle
- f. Left subclavian artery
- g. Right coronary artery
- h. Aortic arch
- i. Left cardiac vein
- j. Superior vena cava
- k. Left common carotid artery
- l. Left pulmonary arteries
- m. Left atrium
- n. Inferior vena cava
- o. Pulmonary trunk
- p. Right atrium

- 30.-33.** Use the terms that follow to identify the heart valves shown in Figure 10-3. (*Note:* In a beating heart, either the two top or the two bottom valves would be open whenever the opposite pair is closed. Figure 10-3, however, gives a better view of all four valves simultaneously.)

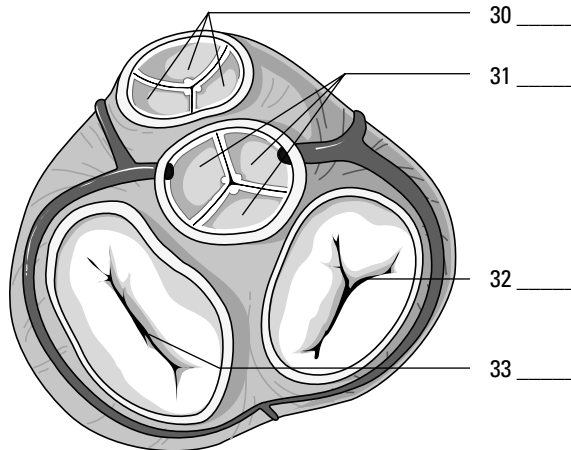


Figure 10-3:
The heart
valves.

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- a. Tricuspid valve
 - b. Pulmonary semilunar valve
 - c. Aortic semilunar valve
 - d. Bicuspid valve
- 34.** The cavity in the heart that contains the areas called the sinus venarum cavarum and a blind pouch called the auricle is the
- a. Left ventricle
 - b. Right atrium
 - c. Left atrium
 - d. Right ventricle
- 35.** The superior vena cava enters the heart by way of the
- a. Left ventricle
 - b. Pulmonary vein
 - c. Right ventricle
 - d. Left atrium
 - e. Right atrium
- 36.** The cusps of the atrioventricular valves are held in place by
- a. Supporting ligaments
 - b. The chordae tendineae
 - c. The trabeculae carneae
 - d. The papillary muscles
 - e. Nothing because they need no supporting structure to hold them

37. The atrioventricular opening between the right atrium and right ventricle is covered by the
- Bicuspid valve
 - Tricuspid valve
 - Mitral valve
 - Semilunar valve
- 38.-42. Match the following descriptions with the proper anatomical terms.
- | | |
|---|-----------------------|
| 38. _____ Returns blood to the heart from the head, thorax, and upper extremities | a. Tricuspid valve |
| 39. _____ Valve located between the right atrium and right ventricle | b. Bicuspid valve |
| 40. _____ Valve located between the right ventricle and pulmonary artery | c. Superior vena cava |
| 41. _____ Returns blood to the heart from the trunk and lower extremities | d. Semilunar valve |
| 42. _____ Valve located between the left atrium and left ventricle | e. Inferior vena cava |

Conducting the Heart's Music

The mighty, nonstop heart keeps up its rhythm because of a carefully choreographed dance of electrical impulses called the *conduction system* that has the power to produce a spontaneous rhythm and conduct an electrical impulse. Four structures play key roles in this dance — the *sinoatrial node*, *atrioventricular node*, *atrioventricular bundle*, and *Purkinje fibers*. (You can see them in Figure 10-4.) Each is formed of highly tuned modified cardiac muscle. Rather than both contracting and conducting impulses as other cardiac muscle does, these structures specialize in conduction alone, setting the pace for the rest of the heart. Following is a bit more information about each one:

- ✔ **Sinoatrial node:** This node really is the pacemaker of the heart. Located at the junction of the superior vena cava and the right atrium, this small knot, or mass, of specialized heart muscle initiates an electrical impulse that moves over the musculature of both atria, causing atrial walls to contract simultaneously and emptying blood into both ventricles. It's also called the *S-A node*, *sinoauricular node*, and *sinus node*.
- ✔ **Atrioventricular node:** The impulse that starts in the S-A node moves to this mass of modified cardiac tissue that's located in the septal wall of the right atrium. Also called the *A-V node*, it directs the impulse to the A-V bundles in the septum.
- ✔ **Atrioventricular bundle:** From the A-V node, the impulse moves into the atrioventricular bundle, also known as the *A-V bundle* or *bundle of His* (pronounced "hiss"). The bundle breaks into two branches that extend down the sides of the interventricular septum under the endocardium to the heart's apex.
- ✔ **Purkinje fibers:** At the apex, the bundles break up into *terminal conducting fibers*, or Purkinje fibers, and merge with the muscular inner walls of the ventricles. The pulse then stimulates ventricular contraction that begins at the apex and moves toward the base of the heart, forcing blood toward the aorta and pulmonary artery.

One of the best ways to detect cardiac tissue under a microscope is to look for undulating double membranes called *intercalated discs* separating adjacent cardiac muscle fibers. *Gap junctions* in the discs permit ions to pass between the cells, spreading the

action potential of the electrical impulse and synchronizing cardiac muscle contractions. Potential problems include *fibrillation*, a breakdown in rhythm or propagation of the impulses that causes individual fibers to act independently, and *heart block*, an interruption that causes the atria and ventricles to take on their own rates of contraction. Usually the atria contract faster than the ventricles.

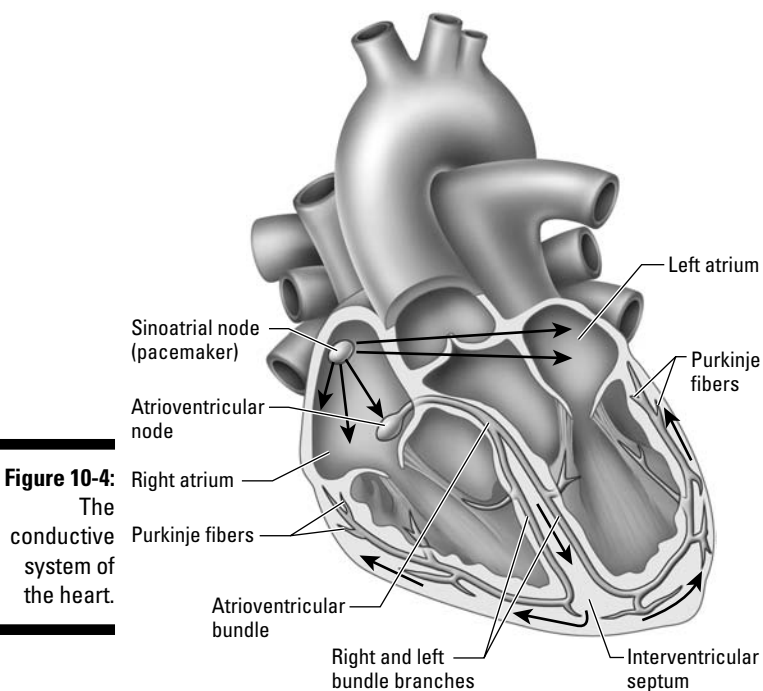


Figure 10-4:
The
conductive
system of
the heart.

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A healthy heart makes a “lub-dub” sound as it beats. The first sound (the “lub”) is heard most clearly near the apex of the heart and comes at the beginning of ventricular systole (the closing of the atrioventricular valves and opening of the semilunar valves). It’s lower in pitch and longer in duration than the second sound (the “dub”), heard most clearly over the second rib, which results from the semilunar valves closing during ventricular diastole. Defects in the valves can cause turbulence or regurgitation of blood that can be heard through a stethoscope. Called *murmurs*, these sounds indicate imperfect closure of one or more valves.

Have you got the beat? Try the following practice questions that deal with the heart’s rhythm:



- Q.** Cardiac tissue is distinctive microscopically because of the presence of
- Hemoglobin
 - Intercalated discs
 - Fibrin
 - Ganglia
 - Nuclei

- A.** The correct answer is intercalated discs.

43. The pacemaker of the heart is also known as the
- Sinoatrial node (S-A node)
 - Extrinsic nerve control center
 - Bundle of His
 - Atrioventricular node (A-V node)
 - Purkinje control fibers
44. Stimulation of myocardial contractions in the ventricles radiates from the
- Bundle of His
 - Atrioventricular bundles
 - Sinoatrial node (S-A node)
 - Purkinje fibers
 - Atrioventricular node (A-V node)
45. Choose the correct conductive pattern.
- S-A node → Bundle of His → A-V node → Purkinje fibers
 - A-V node → S-A node → Purkinje fibers → Bundle of His
 - S-A node → A-V node → Bundle of His → Purkinje fibers
 - S-A node → Purkinje fibers → Bundle of His → A-V node

Riding the Network of Blood Vessels



Blood vessels come in three varieties, which you can see illustrated in Figure 10-5:

- ✓ *Arteries* carry blood away from the heart. The largest artery is the aorta. Small ones are called *arterioles*, and microscopically small ones are called *metarterioles*.
- ✓ *Veins* carry blood toward the heart; all veins except the pulmonary veins contain deoxygenated blood. Small ones are called *venules*, and large venous spaces are called *sinuses*.
- ✓ Microscopically small *capillaries* carry blood from arterioles to venules, but sometimes tiny spaces in the liver and elsewhere called *sinusoids* replace capillaries.

The walls of arteries and veins have three layers: the outermost *tunica externa* (sometimes called *tunica adventitia*) composed of white fibrous connective tissue, a central “active” layer called the *tunica media* composed of smooth muscle fibers and yellow elastic fibers, and an inner layer called the *tunica intima* made up of endothelium that aids in preventing blood coagulation by reducing the resistance of blood flow. Arterial walls are very strong, thick, and very elastic to withstand the great pressure to which the arteries are subjected. Arteries have no valves.

There are two types of arteries: elastic and muscular. In elastic arteries, found primarily near the heart, the tunica media is composed of yellow elastic fibers that stretch

with each systole and recoil during diastole; essentially they act as shock absorbers to smooth out blood flow. In muscular arteries, the tunica media consists primarily of smooth muscle fibers that are active in blood flow and distribution of blood. The larger blood vessels have smaller blood vessels, the *vasa vasorum*, that carry nourishment to the vessel wall.

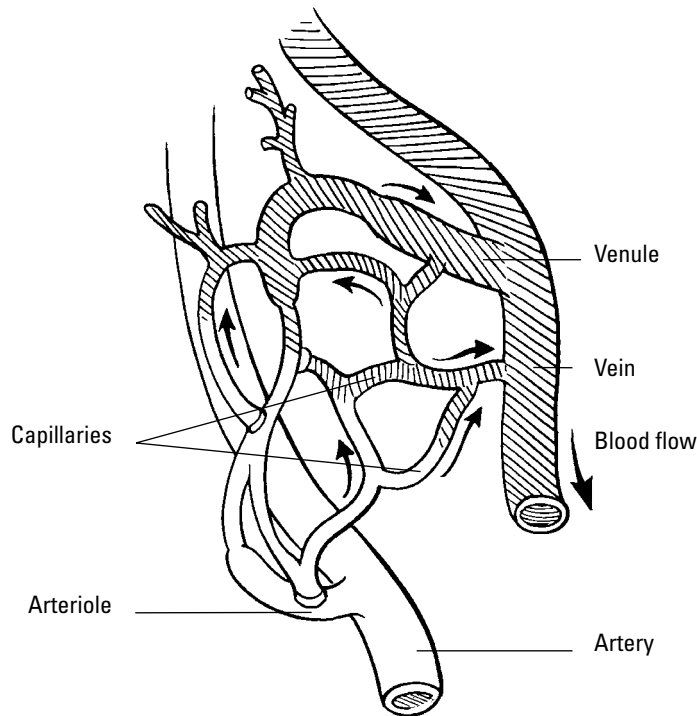


Figure 10-5:
The
capillary
exchange.

While larger in diameter than arteries, veins have thinner walls and are less distensible and elastic. Veins that carry blood against the force of gravity, such as those in the legs and feet, contain valves to prevent backsliding into the capillaries. Normally the blood that veins are returning to the heart is unoxygenated (contains carbon dioxide); the one exception is the pulmonary vein, which returns oxygenated blood to the heart from the lungs.

Capillaries are breathtakingly tiny and capable of forming vast networks, or capillary beds. Their walls are a single layer of squamous endothelial cells. Precapillary sphincters take the place of valves to regulate blood flow. All exchange occurs at the capillaries.

Blood from the digestive tract takes a detour through the hepatic portal vein to the liver before continuing on to the heart. Called the *hepatic portal system*, this circuitous route helps regulate the amount of glucose circulating in the bloodstream (see Figure 10-6). As the blood flows through the sinusoids of the liver, *hepatic parenchymal cells* remove the nutrient materials. *Phagocytic* cells in the sinusoids remove bacteria and other foreign materials from the blood. The blood exits the liver by the hepatic veins, which carry it to the inferior vena cava, which ultimately returns it to the heart.

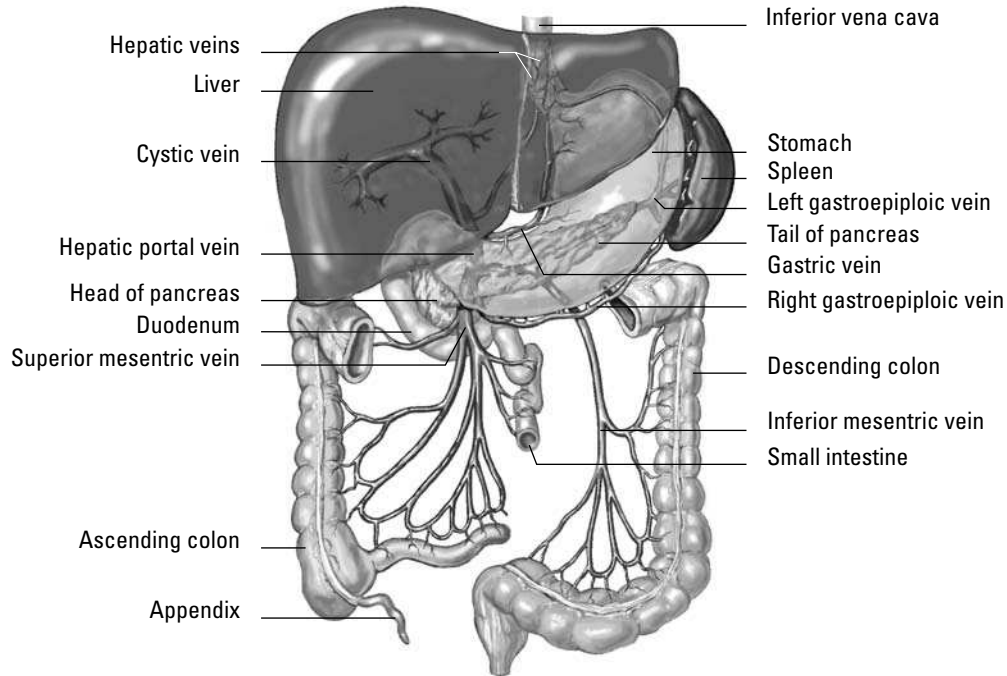


Figure 10-6:
The veins of
the hepatic
portal
system.

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Beating from the Start: Fetal Circulation

Because nutrients and oxygen come from the mother's bloodstream, fetal circulation requires extra vessels to get the job done. Two umbilical arteries — the *umbilical vein* and the *ductus venosus* — fill the bill. Fetal blood leaves the placenta through the umbilical vein, which branches at the liver to become the *ductus venosus* before entering the inferior vena cava that carries blood to the right atrium and then through a hole in the septum called the *foramen ovale* into the left atrium. From there it flows into the left ventricle and is pumped through the aorta to the head, neck, and upper extremities. It returns to the heart through the superior vena cava, to the right atrium, to the right ventricle, to the pulmonary trunk (lungs inactive), goes through the ductus arteriosus into the aorta, to the abdominal and pelvic viscera and lower extremities, and to the placenta through the umbilical artery. After birth, these circulation pathways quickly shut down, eventually leaving a depression in the septum, the fossa ovale, where the hole of the foramen ovale once was.

Now is your chance to practice circulating through the circulatory system:

- 46.** In fetal hepatic portal circulation, blood flows directly into the systemic circulation through the
- Conus arteriosus
 - Hepatic vein
 - Ductus venosus
 - Ductus arteriosus
 - Truncus arteriosus

- 47.** Follow a drop of blood through the heart, starting in the superior vena cava. Number the following structures in sequential order.
- ___ Pulmonary vein
 - ___ Right ventricle
 - ___ Lung
 - ___ Right atrium
 - ___ Pulmonary artery
- 48.** Number the structures in the correct sequence of blood flow from the heart to the radial artery for pulse. Start at the heart with the aortic semilunar valve.
- ___ Axillary artery
 - ___ Subclavian artery
 - ___ Ascending aorta
 - ___ Brachial artery
 - ___ Aortic arch
- 49.** Number the structures in the correct sequence of blood flow from the forearm to the heart.
- ___ Basilic vein
 - ___ Subclavian vein
 - ___ Superior vena cava
 - ___ Brachial vein
 - ___ Axillary vein
- 50.** Number the structures in the correct sequence of blood flow from the great saphenous vein back to the heart.
- ___ External iliac vein
 - ___ Right atrium
 - ___ Common iliac vein
 - ___ Femoral vein
 - ___ Inferior vena cava
- 51.** Follow a drop of blood from the right atrium to the radial artery (for pulse). Number the structures in sequential order.
- 1 Right atrium
 - ___ Pulmonary artery
 - ___ Left atrium
 - ___ Bicuspid valve
 - ___ Ascending aorta
 - ___ Axillary artery
 - ___ Radial artery
 - ___ Right ventricle

- Pulmonary vein
- Aortic semilunar valve
- Brachial artery
- Tricuspid valve
- Lung capillary
- Aortic arch
- Pulmonary semilunar valve
- Left ventricle
- Subclavian artery

52. Follow a drop of blood from the stomach to the inferior vena cava. (Remember the portal system?) Number the structures in sequential order.

- 1 Superior mesenteric vein
- Sinusoids of liver
- Hepatic vein
- Hepatic portal vein
- Inferior vena cava

53. Follow a drop of blood from the aortic semilunar valve of the heart to the forearm and back to the heart. Number the structures in sequential order.

- 1 Ascending aorta
- Basilic vein
- Axillary artery
- Subclavian vein
- Brachial vein
- Radial artery
- Right atrium
- Brachial artery
- Axillary vein
- Capillaries in the hand
- Superior vena cava
- Subclavian artery
- Aortic arch

54. Follow a drop of blood from the saphenous vein back to the heart. Number the structures in sequential order.

- 1 Saphenous vein
- External iliac vein
- Inferior vena cava
- Right atrium
- Femoral vein
- Common iliac vein
- Right ventricle

55. Follow a drop of blood from the anterior tibial vein to the lungs. Number the structures in sequential order.

- 1 Anterior tibial vein
- External iliac vein
- Inferior vena cava
- Right ventricle
- Popliteal vein
- Common iliac vein
- Pulmonary artery
- Femoral vein
- Right atrium
- Lung capillaries