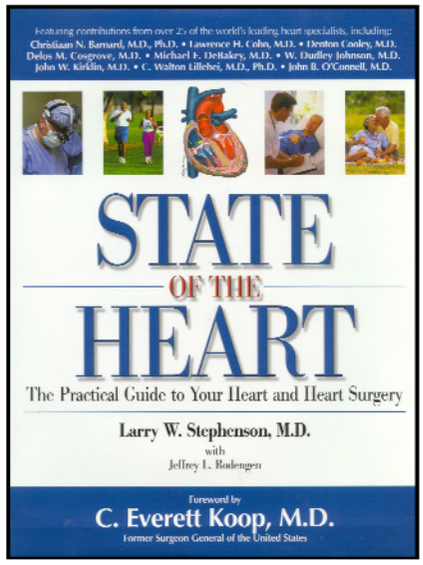

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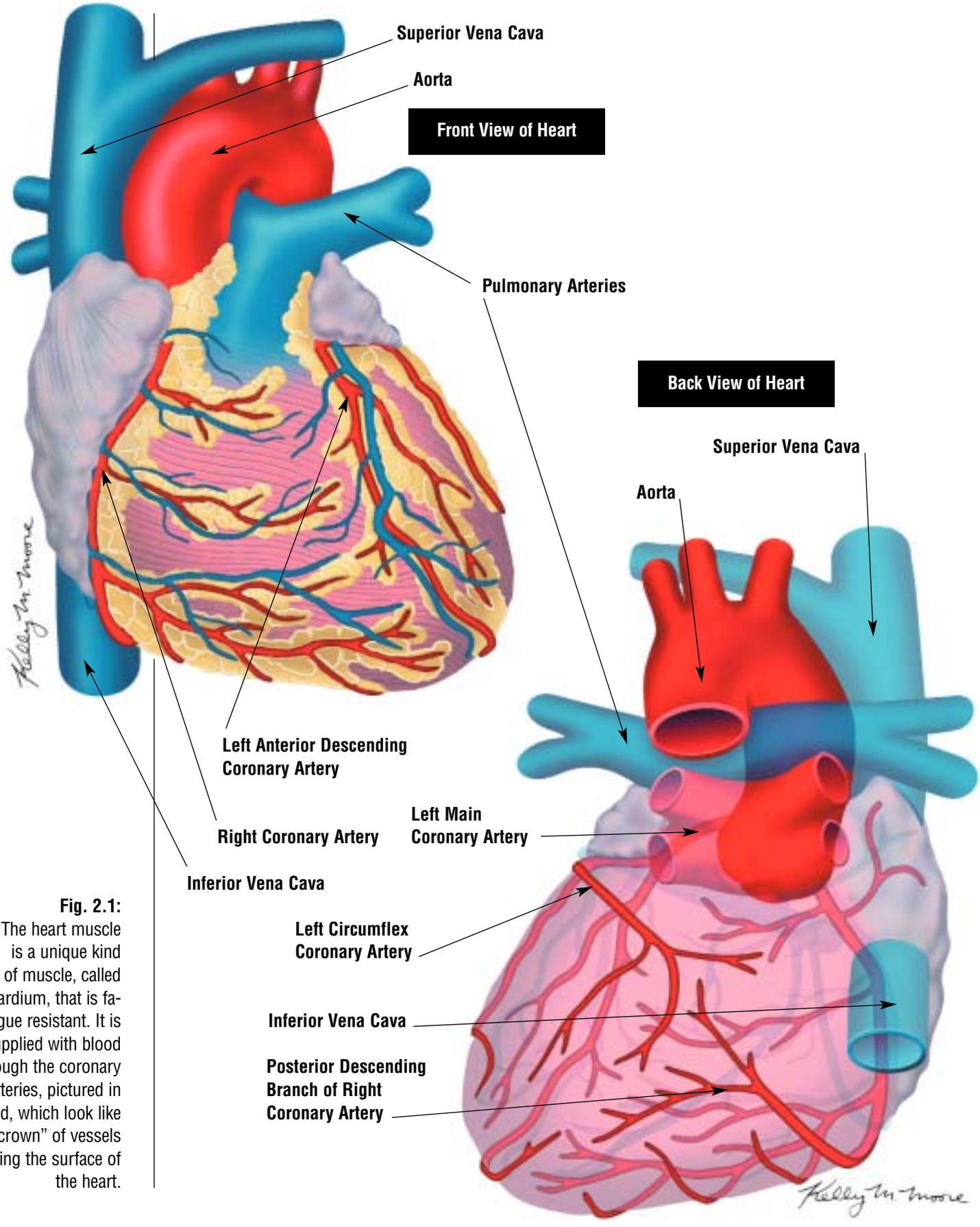


Fig. 2.1: The heart muscle is a unique kind of muscle, called myocardium, that is fatigue resistant. It is supplied with blood through the coronary arteries, pictured in red, which look like a "crown" of vessels covering the surface of the heart.

CHAPTER TWO

THE NORMAL HEART

THE HEART SITS AT THE CENTER of the incredible network of **arteries** and **veins** whose job it is to nourish your organs and tissues with blood. Of all your muscles, your heart is perhaps the most durable — it is expected to perform continuously without missing a beat for your entire life. Imagine your heart as a very efficient machine. It helps convert the food you eat into mechanical energy, which is then used to pump blood first through the lungs, where it receives oxygen, and then throughout the rest of the body.

Your heart is about the size of your fist and rests slightly to the left of center under your breastbone or sternum. It has four chambers: the two upper chambers are filling chambers, or atria, and the two lower chambers are powerful pumping chambers called ventricles. The ventricles are separated by a common wall called the interventricular **septum**, and the atria are separated by the atrial septum. These common walls, like the rest of the heart, are composed of heart muscle called myocardium.

The Right Side of the Heart

Blood begins its journey toward the heart in millions of tiny blood vessels called **capillaries** throughout the body. Capillaries are the smallest elements of the circulatory system and are where the transfer of oxygen and nutrients from blood to the body's tissues occurs. After the blood gives off the oxygen in the capillaries, it turns a dark red to purple color. The red blood cells in the capillary then pick up the carbon dioxide molecules that are the byproducts of cell and tissue function.

Capillaries feed into small veins, which in turn feed into larger veins as blood moves closer to the heart. The veins from the abdomen and lower body drain into the inferior vena cava. This large vein is about the same diameter as your thumb and drains directly into the right atrium. The blood returning from the chest and upper body drains into the superior vena cava, also about the diameter of your thumb. It, too, drains into the right atrium (Fig. 2.1).

When the unoxygenated blood reaches the right atrium, it flows through the tricuspid valve into the right ventricle (Fig. 2.2). Like the other three heart valves, the tricuspid valve is a one-way valve and does not allow blood to flow backwards (Fig. 2.3).

After the right ventricle fills with blood, it begins to contract, forcing blood out

Artery:
A blood vessel that carries blood from the heart to the body or from the heart to the lungs.

Vein:
A vessel that channels blood from the capillaries back to the heart.

Septum:
A wall that separates two chambers, such as two chambers of the heart.

Capillaries:
The smallest elements of the circulatory system. Capillaries are where the transfer of oxygen and nutrients from blood to the body's tissues occurs.

The Heart as a Muscle

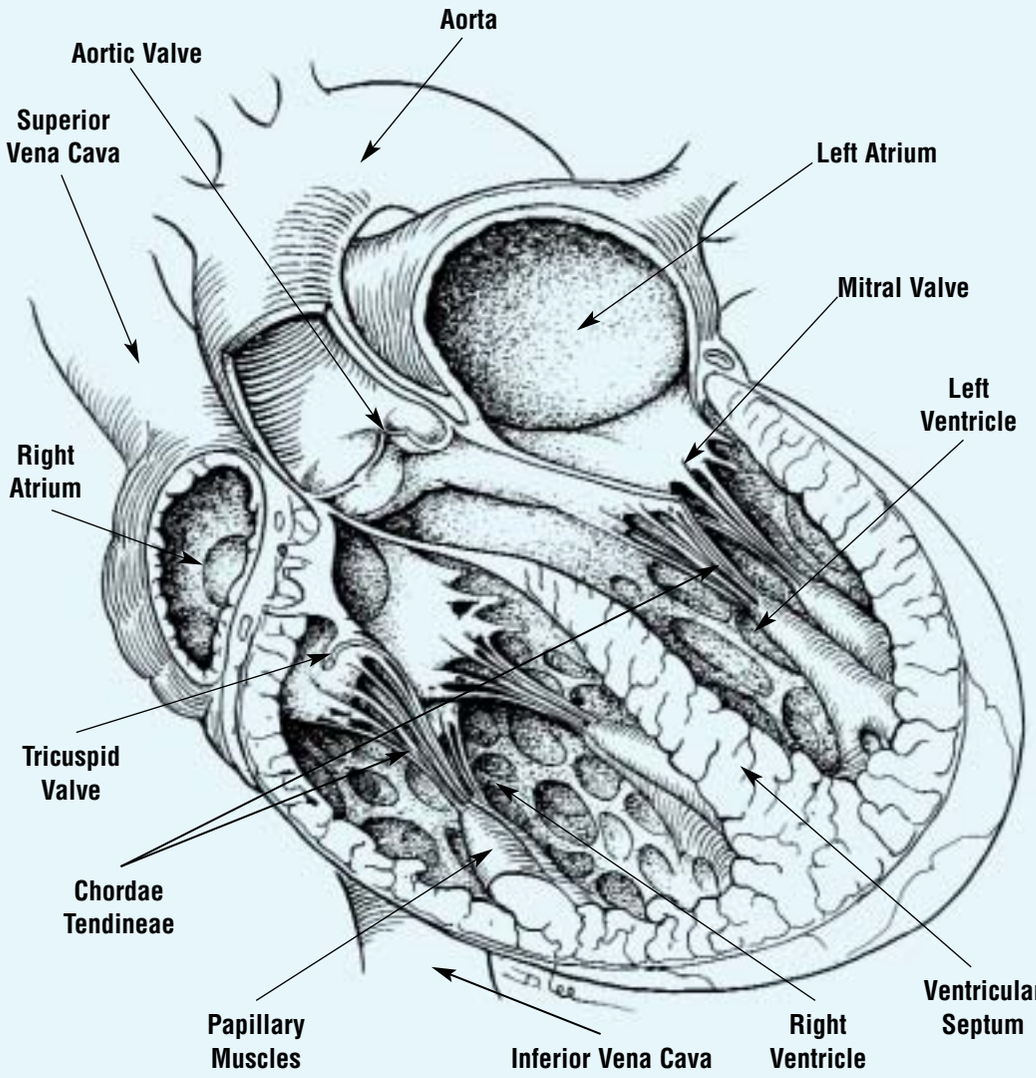


Fig. 2.2: The heart is a remarkably resilient muscle. Shown in a cut-away view, the chambers and valves, with their chordae tendineae, are clearly visible.

THE BODY CONTAINS THREE types of muscles, one of which is cardiac muscle, or myocardium. The heart is mainly composed of myocardium, which has unique properties that make it able to meet the demands placed on it.

Unlike other types of muscle, myocardial muscle is relatively fatigue-resistant. In an adult, the heart beats about seventy times a minute, or more than one hundred thousand times in a single day. Incredibly, it never gets tired. The heart pumps about five to seven quarts of blood a minute. Over a lifetime, the heart of a person at rest pumps enough fluid to fill a supertanker ship with a million barrels. Since the heart pumps much more blood when a person is active, the actual amount of fluid pumped during a life would be even greater.

through the pulmonary valve into the pulmonary artery. Pulmonary means "lung related," and arteries are responsible for carrying blood away from the heart. The pulmonary artery carries blood into the lungs. The pulmonary arteries are a unique element of the circulatory system because the pulmonary arteries carry unoxygenated blood, whereas the rest of our arteries carry oxygenated blood.

In the lung, carbon dioxide molecules are given off by the red blood cells. These tiny molecules travel through the capillary wall into small air sacs called **alveoli** (Fig. 2.4). In turn, the oxygen that we breathe in moves through the alveoli wall and is taken up by the blood. The newly oxygenated blood next passes into the pulmonary veins, which carry the oxygenated blood back to the heart. This oxygenated blood is bright red.

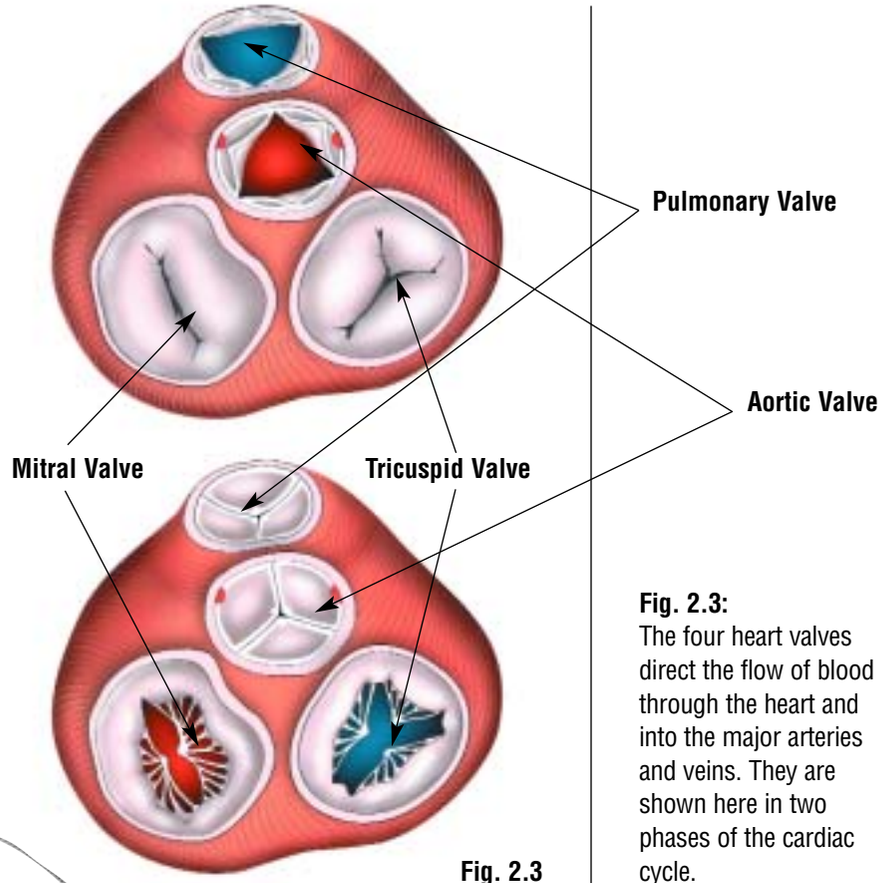


Fig. 2.3

Fig. 2.3:
The four heart valves direct the flow of blood through the heart and into the major arteries and veins. They are shown here in two phases of the cardiac cycle.

Fig. 2.4

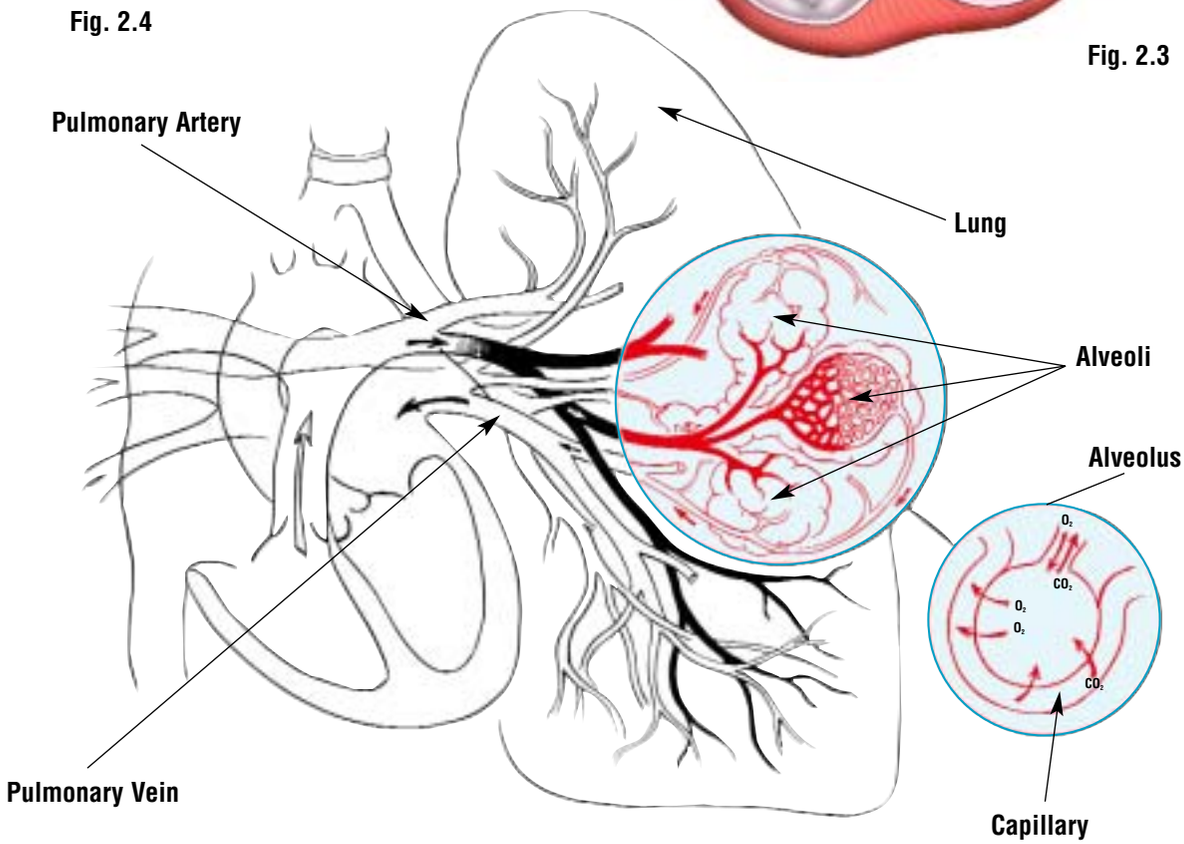


Fig. 2.4:
Oxygen transfer takes place in the lungs through the thin membranes of the **alveoli**. When the blood vessels release carbon dioxide, it passes back through the alveoli and is exhaled during respiration.

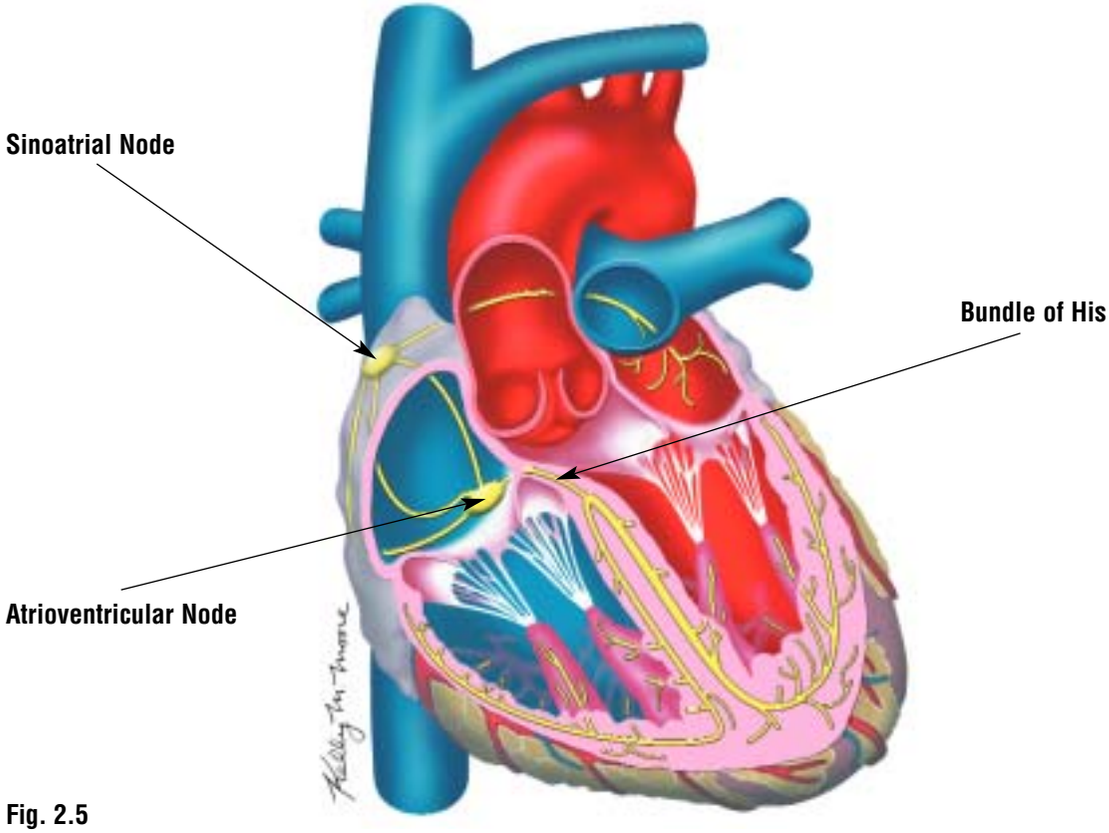


Fig. 2.5

Fig 2.5: The heart's beat is caused by an electrical impulse that travels from the S-A, or sinoatrial, node to the A-V, or atrioventricular, node and through the specialized heart muscle.

The Left Side of the Heart

Blood returning through the pulmonary veins empties into the left atrium. Some of the oxygen is contained in fluid, or plasma, but most is contained in the red blood cells, which are designed to carry oxygen. Once in the left atrium, blood flows through another one-way valve called the mitral valve into the left ventricle.

The left ventricle is the heart's main pumping chamber. As the left ventricle contracts, the mitral valve closes and the aortic valve opens. Blood is forced through the one-way aortic valve into the aorta, which is the main artery of the body and somewhat larger than your thumb.

The aorta first heads upward toward the neck, then makes a U-turn at the top of the chest just before the neck and heads down through the chest and into the abdomen toward the pelvis. It divides into two arteries, known as iliac arteries, which supply the pelvis and legs with oxygenated blood. In the chest and abdomen, the aorta gives off numerous branches to supply blood to the brain, the heart muscle itself, and other organs, muscles, and tissues.

Systole: Means the heart is contracting. It usually means the ventricles are contracting, but it can also refer to atrial contraction.

Diastole: The portion of the cardiac cycle in which the heart is relaxed.

Blood Pressure

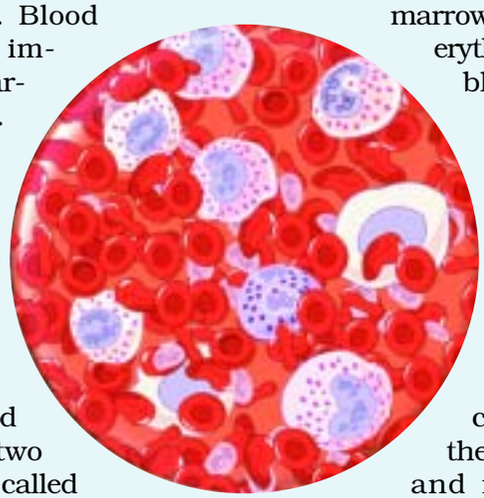
The heart forces blood into the aorta under pressure, which can be measured and is called your blood pressure. Blood pressure depends on the strength of the heart's contraction and the number of beats per minute. It also depends on the volume of blood in the heart and blood vessels and the elasticity of the arteries.

There are two phases of blood pressure. When the heart is contracting, the highest pressure generated in the heart and arteries is known as **systolic pressure**. As the heart relaxes, blood pressure declines, and the lowest pressure level is known as **diastolic pressure**. For example, if blood pressure is recorded as "120 over

THE BLOOD

BLOOD IS A VERY COMPLEX fluid that both feeds and cleanses the body. It is the means by which oxygen, tiny food particles, and other nutrients are delivered to tissue and, conversely, waste products are removed and eventually discarded by the lungs, liver, and kidneys.

The blood consists of plasma, which is a straw-colored solution, and three formed elements suspended in the plasma: red blood cells, white blood cells, and platelets. Blood travels through an immense network of arteries and veins. Arteries typically carry bright red, oxygenated blood from the heart to the tissues, whereas veins carry dark purple, unoxygenated blood back to the heart. The tiniest blood vessels linking the two kinds of vessels are called capillaries. Capillaries are so small that blood cells travel through some capillaries in single file. The diameter of a capillary can be as small as three or four microns — and there are approximately twenty-five thousand microns in an inch!



The amount of blood in your body depends on your size and some other factors. A person of 160 pounds has about five quarts of blood.

Plasma is mostly water but contains hundreds of other substances, including proteins, digested food, waste products, and electrolytes, which are mainly minerals in solution. There are substances in blood that cause clotting in response to injury. There are also dissolved gases and chemical transmitters called hormones. Hormones, which originate in various glands, activate or deactivate certain bodily functions.

Serum is a term often confused with plasma. Serum is plasma that has had the clotting elements removed.

Each of the three formed elements in blood has a specific function. Red blood cells are produced in the bone marrow and are also called erythrocytes. One ounce of blood contains billions of red blood cells. Their main job is to carry oxygen from the lungs to the body and to carry carbon dioxide from the tissues to the lungs.

White blood cells are also called leukocytes and help protect the body against disease and infection. They are somewhat larger than the red blood cells and are also produced in the bone marrow. There are several types of white blood cells, each with a different function. There are millions of white blood cells per ounce of blood.

Platelets are disk-shaped structures produced in the bone marrow. They are much smaller than red or white blood cells. They are responsible for helping to stop bleeding if a blood vessel is damaged. They clump or stick together around the edges of a damaged blood vessel. As they pile up, they form a seal that helps to start the blood-clotting process so a permanent plug can form.

White Blood Cell

Red Blood Cell

Platelet

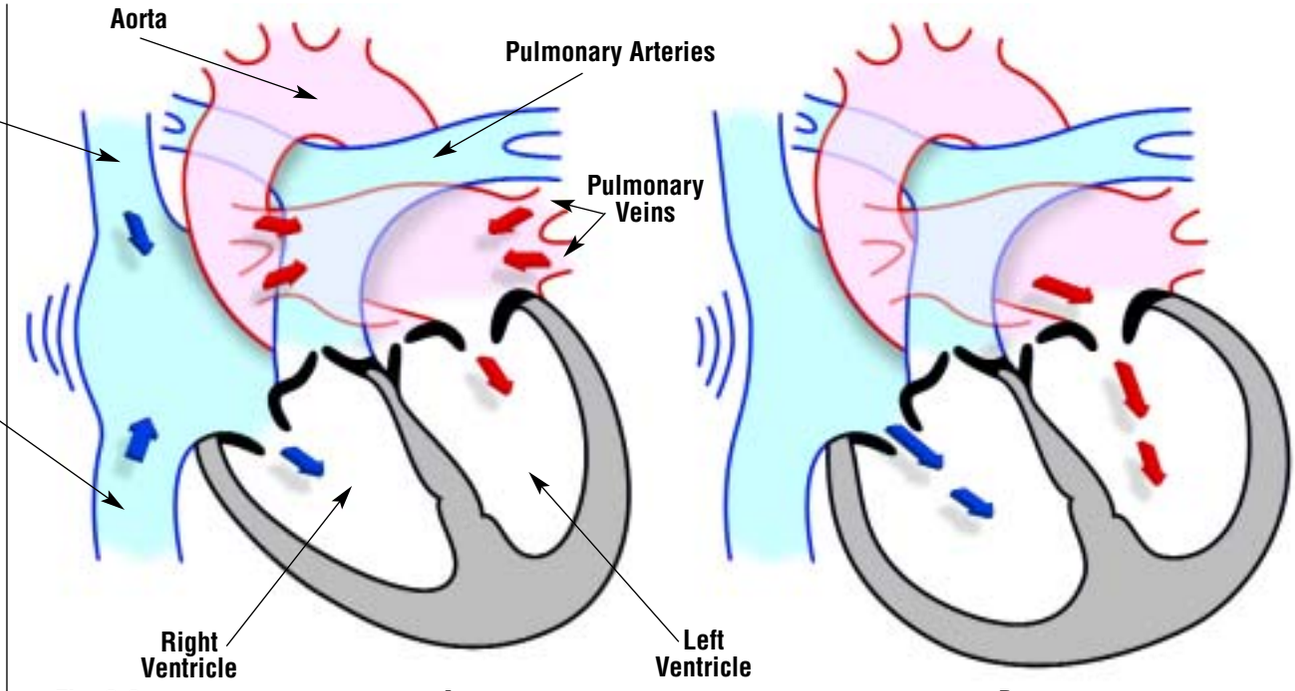


Fig. 2.6

Sinoatrial Node: Also referred to as the sinus node, or S-A node. This is the true pacemaker of the heart. Its cells rhythmically discharge electrical impulses that cause the heart to contract. These impulses also travel to the A-V node.

Atrioventricular Node: A specialized nerve-type tissue located in the wall of the right ventricle, also called the A-V node. It receives electrical impulses from the sinoatrial node that cause it to relay electrical impulses that cause the heart to contract.

Bundle of His: A special nerve-type tissue extending from the atrioventricular node (A-V node) along the ventricular septum. It helps conduct electrical impulses from the A-V node through the ventricles.

80 mmHg," the highest pressure in the artery measured during systole is 120 and the lowest pressure, recorded in your arteries while the heart is relaxing, is 80.

When you visit your doctor's office, the doctor or nurse will use a device placed around your right or left arm to measure your pressure. This blood pressure cuff and the device it is attached to are called a sphygmomanometer. Its reading is valuable because it can tell your doctor various things about the condition of your heart and arteries.

The Electrical Conduction System

Heart muscle has another unique quality. The fibers that make up the heart muscle are connected by electrical conduction mechanisms called intercalated disks. These allow current to flow from one muscle-fiber cell to another so if one part of the heart is stimulated, the current will flow through all of the heart muscle, causing the entire heart to contract.

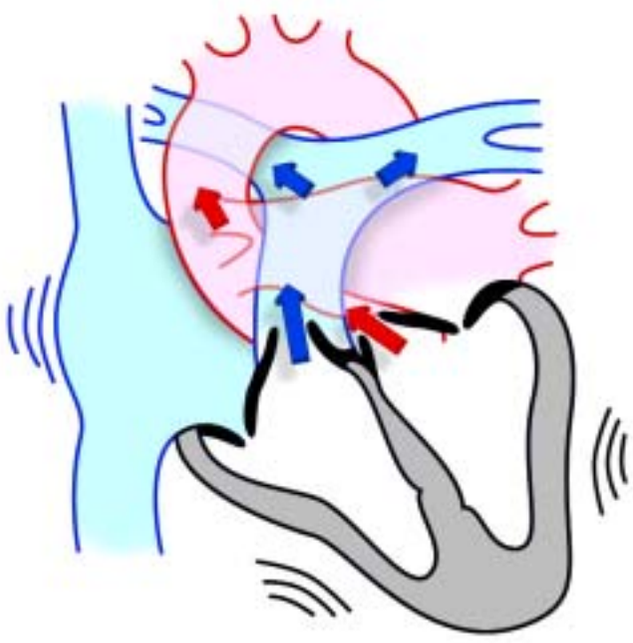
The heart has its own natural "pacemaker" system to regulate your heartbeat (Fig. 2.5). The main pacemaker for the heart is located at the junction of the right atrium and superior vena cava. It is called the **sinoatrial node** or S-A node. This S-A node sets the rhythm of heart beats.

Its electrical impulse spreads through the atrium to a second area of conducting tissue located between the atria and the ventricles known as the **atrioventricular node** or A-V node. The electrical impulse travels through the A-V node along a main bundle of special nerve-type fibers called the **bundle of His** (pronounced "hiss") and from there throughout the ventricles.

This electrical impulse moves through the heart with blinding speed, causing the heart to contract as a single unit. If something happens to the S-A node, such as disease or traumatic injury, the A-V node can take over as the heart's pacemaker.

The Cardiac Cycle

There are different phases to a healthy heartbeat, or cardiac cycle. During the first phase, the heart is relaxed and blood



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flows from the venae cavae into the right atrium and from the pulmonary veins into the left atrium. The tricuspid and mitral valves open, then blood flows from the atria into the ventricles (Fig. 2.6A).

In the next phase, the atria contract and force more blood through the tricuspid and mitral valves, which "tops up" the ventricles. This is called atrial systole (Fig. 2.6B).

Next, the right and left ventricles contract. This is called ventricular systole. The mitral and tricuspid valves shut and the pulmonary and aortic valves open as blood travels into the pulmonary artery and the aorta (Fig. 2.6C).

When the ventricles complete their contraction phase, the pulmonary and aortic valves close. The atria expand again and fill with blood. The ventricles relax and the tricuspid and mitral valves open, completing one cardiac cycle and beginning another. If the heart is beating sixty times per minute, all of this is accomplished in one second.

In an adult at rest, a heart rate of seventy beats per minute is fairly typical. If you're exercising, such as running, weightlifting, swimming, or playing tennis, your heart rate increases to supply more blood to your muscles, which need more oxygen and nutrients as they work.

Fig. 2.6: During the phases of a single heartbeat, or cardiac cycle, blood flows into the atria (A), through the tricuspid and mitral valves into the ventricles (B), and then is ejected forcefully into the pulmonary artery and aorta (C). A typical heartbeat takes less than a second.

The Coronary Arteries

As the heart rate increases and more blood is required by the body, the heart muscle itself needs more oxygen. Coronary arteries are the arteries that supply the heart muscle with oxygenated blood. Typically, there are two coronary arteries that branch off the aorta (Fig. 2.1). The right coronary supplies blood to the right ventricle and usually a portion of the interventricular septum. The left coronary or left main coronary immediately divides into two large branches, the left anterior descending coronary and the left circumflex coronary, which supply blood to the left ventricle.

Unoxygenated blood is drained from the heart muscle by a network of coronary veins. Most of these gather in a larger vein called the coronary sinus, which empties the unoxygenated blood into the right atrium.

Much of the heart disease in the United States is caused by blockages of the coronary arteries, and therefore maintaining healthy coronary arteries is a major means of preventing this type of heart disease.

What You Should Know About Your Heart During Pregnancy

By
Pamela R. Gordon, M.D., F.A.C.C.
Associate Professor of Internal Medicine
Division of Cardiology
Wayne State University
Detroit, Michigan
and
a Mother of Three

PREGNANCY POSES A SPECIAL challenge to the mother's cardiovascular system. Unlike other vital organs such as the brain or the kidneys, the mother's heart must increase the amount of blood pumped to provide blood to the growing fetus and placenta. The increase is tremendous during the pregnancy and becomes intense during labor and delivery.

Pregnancy is also associated with symptoms that mimic heart disease. Pregnant women often complain of chest pain, leg swelling, and shortness of breath. In women who are not pregnant, these may signal an underlying cardiac problem.

For the woman born with heart disease or who develops heart disease in young adulthood, pregnancy-related risks may increase from the extra demands on the heart. Pregnancy may also unmask a previously undiagnosed heart problem. However, with few exceptions, the majority of women, even those with heart disease, are able to safely complete their pregnancy with proper, specialized prenatal care.

Cardiovascular Physiology

In the first three months of pregnancy, a woman's blood volume rises rapidly. This increase continues into mid-pregnancy, then slows down. The average overall increase in blood volume is 50 percent but varies among individuals and is connected to fetal weight, placental size, and maternal weight gain. As a result, larger increases are seen in multiple pregnancies (twins or more).

The number of red blood cells, however, does not increase as fast as the circulating blood volume, which explains why many women develop a relative anemia — the "physiologic anemia of pregnancy." In a woman with normal hemoglobin before conception, a slight drop is average and inconsequential. For the woman who begins her pregnancy with anemia, iron supplementation may help correct a major drop.

Along with the increased blood volume, one of the more dramatic changes that occurs in pregnancy is an increase in cardiac output — that is, the amount of blood pumped from the heart each minute. This is due to the raised blood volume and faster heart rate (an average increase of ten to twenty beats per minute). The maximum increase in cardiac output occurs by approximately twenty-four weeks after conception, after which it plateaus.

On average, the increase in cardiac output during pregnancy is 50 percent for a single pregnancy and increases with multiple fetuses. It is estimated that with triplets, the heart at least doubles its output. Therefore, a heart that before pregnancy pumped six quarts each minute would be pumping twelve quarts each minute in the fifth month of pregnancy!

This rise in blood volume and cardiac output, which increases the work of the heart as it supplies oxygen-rich blood to a greater body mass, is partly counterbalanced by lowered blood pressure. Hormonal changes early in pregnancy relax blood vessels, which in turn lowers blood pressure so the heart doesn't have to work quite so hard. This decrease is greater in the diastolic pressure (the bottom number of the blood pressure measurement). Later in pregnancy, the growth of blood supply to the uterus and placenta further contributes to this decrease.

A common problem in an otherwise uncomplicated pregnancy is high blood pressure, or pregnancy-induced hypertension. This condition is thought to occur from inadequate uteroplacental blood flow and, if untreated, is associated with low birth weight and serious maternal consequences. Fortunately, it can be treated by the use of low-dose aspirin.

The Last Trimester

The majority of these changes occur in the first six months and stabilize in the last three months. At that point, body position becomes an important factor. The enlarged uterus exerts pressure on the veins of the pelvis and lower extremities, decreasing blood return to the heart, which results in decreased cardiac output. This is most pronounced when the mother is lying on her back. In up to 10 percent of women, there may be a profound drop in blood pressure and heart rate, causing the woman to pass out. Referred to as the Supine Hypotensive Syndrome of Pregnancy (SHSOP), it is promptly relieved by rolling onto the side, which restores normal blood return. This is the major reason for recommending that late-term women sleep on their left sides.

This posture-dependent decrease in blood return in the third trimester may also reduce the heart's ability to increase output during strenuous exercise.

Labor and Delivery

Labor places additional demands on the heart. A single strong contraction forces an extra pint of blood into the circulation. Blood pressure increases substantially, especially while pushing, and is influenced by pain and anxiety. The amount of oxygen consumed by a woman in labor increases three-fold. Pain relief and anesthesia reduce these effects of labor and may be especially helpful in the woman with underlying heart disease.

After delivery, complete return to normal cardiovascular status requires weeks. However, there is an immediate and large increase in blood volume soon after delivery as blood shifts from the uterus back to circulation and pressure on the veins is relieved. Cardiac output falls substantially and nearly to normal within twenty-four hours.

The "Symptoms" of Pregnancy, and Warning Signs of Cardiac Disease

The pregnant woman often comes to the doctor's office complaining of symptoms that mimic those of heart disease. Although an examination may reveal signs of abnormal cardiac anatomy or function, it is essential that the physician know the normal signs and symptoms of pregnancy, as well as conduct a thorough history and physical exam. If questions remain after the exam, additional testing or consultation may be necessary.

There are many normal signs of pregnancy. Pregnant women are typically tired. Early in pregnancy, an increase in the hormone progesterone leads to sleepiness. Later in pregnancy, anemia and weight gain contribute to fatigability. The majority of women also complain of shortness of breath, or "dyspnea," by the third trimester. This may be only a "hyperawareness" of breathing rather than true breathlessness or air hunger. It is normal to hyperventilate in pregnancy, again an effect of progesterone. There is also restriction of the diaphragm, which is the muscle used for breathing, by the enlarged uterus, especially when lying down. This may cause the patient to complain of "orthopnea," or difficulty breathing when lying down that improves in the upright position. Any of these symptoms requires careful questioning, and, if excessive, condi-

tions such as heart failure or low cardiac output need to be evaluated further.

Chest pain, the hallmark of coronary artery disease, is a common complaint during pregnancy. Fortunately, pregnant women are in an age group with a low risk of atherosclerotic coronary disease. More likely causes of chest pain include esophageal reflux (heartburn) or pressure on the rib cage. Typical angina pectoris, the type of chest pain caused by blocked coronary arteries, can be easily distinguished from other causes by history alone.

Many women feel their heart beating during pregnancy. It is usually an exaggerated awareness of the heart beating due to the extra blood volume and perhaps a higher heart rate. During pregnancy, the heart is displaced upward and closer to the chest wall, which also may add to the sensation. Only when the palpitations are coupled with extreme elevations in heart rate, or with lightheadedness, fainting, or chest pain, should a potentially dangerous heart rhythm be suspected. Outpatient heart rhythm monitoring can rule out an abnormality and reassure both patient and physician. If an abnormality is detected and treatment is considered, there are multiple available and safe therapies.

Lightheadedness and fainting are not unusual during pregnancy. Nausea from early hormonal changes may trigger dizziness. Also, the uterine pressure on the veins causes pooling of the blood in the legs. The pregnant woman may not easily adjust to movement because venous return to the heart is limited. If fainting occurs unrelated to body position or after exercise, additional investigation is warranted.

Also typical during pregnancy, evaluation with a stethoscope of the increased cardiac output will reveal new sounds. Flow through the enlarged mammary arteries to the breasts, known as the "mammary soufflé," may also be heard. Veins throughout the body, especially in the neck, may appear full or engorged. Leg swelling (edema) eventually develops in most women because of the increased pressure on the veins of the legs and pelvis. This "dependent" edema should improve with leg elevation (above the level of the heart) and should not involve the face and arms.

Safe Tests during Pregnancy

If there are concerns about heart disease based on symptoms or physical findings, diagnostic tests may be performed that are safe for the developing fetus. An electrocardiogram can diagnose abnormal heart rhythm. A twenty-four-hour monitor or "loop recorder" over weeks may detect an abnormal heart rhythm. A chest x-ray can be performed with proper shielding to protect the fetus.

The most useful test is cardiac ultrasound, or echocardiography, which provides information with regard to cardiac size, function, and structure, as well as blood flow patterns. An echocardiogram can evaluate heart valve abnormalities, causes of heart failure, and a multitude of other cardiac problems. Exercise stress testing and even cardiac catheterization may be performed, if necessary, without serious risks to the fetus. Only cardiac testing that uses radionuclides (e.g., thallium) should always be avoided.

Pregnancy in the Woman with Heart Disease

Before becoming pregnant, a woman may have a congenital heart defect or acquired heart disease. Many congenital defects can now be surgically repaired in infancy, and the first generation of these patients has only recently reached childbearing age. They represent a new kind of patient for obstetricians and cardiologists.

Acquired heart disease in pregnant women includes primarily rheumatic disease involving heart valves, heart failure, and coronary artery disease. Because many women are now delaying pregnancy until they are older, acquired heart disease is somewhat more common in pregnant women than earlier in this century.

When considering pregnancy in the presence of heart disease, the most important factor is the severity of the heart-related symptoms. In general, patients without symptoms or those only slightly symptomatic enjoy a good outlook for both mother and fetus.

In the moderately or severely symptomatic patient, both maternal and fetal health are at high risk. Thorough evaluation by history, physical examinations, and diagnostic testing will allow the physician to assess the risk of pregnancy to mother and fetus. For the patient who requires drug therapy, consideration of risk to the fetus is especially important. Fortunately, many cardiac drugs can be safely administered during pregnancy.

In some cases, intervention such as coronary artery angioplasty (balloon dilatation of a coronary artery) or surgical repair of a valve may be necessary for maternal survival and cannot be delayed until after delivery. Although risk to the fetus is increased, many of these procedures have been successfully performed with a good outcome for both mother and fetus.