CHAPTER 10

DIAGNOSIS

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INTRODUCTION

Over the past thirty years, the ability to diagnose heart disease has improved dramatically, largely because of the evolution of new, increasingly sophisticated cardiac-testing techniques that include electrocardiography, exercise stress testing, radioisotope studies, echocardiography, and cardiac catheterization.

Despite these technological advances, the initial diagnosis of heart disease is still supported by two low-technology, low-cost cornerstones: the medical history and physical examination. When carefully performed and properly interpreted, the history and the physical will yield an accurate diagnosis in many, if not the majority of cases. Signs and symptoms such as chest pain, shortness of breath, and an abnormal pulse, coupled with detailed cardiopulmonary examination and a careful history that may reveal major risk factors, have proved over and over their value in establishing a diagnosis.

After an initial presumptive diagnosis is made based on the findings of the history and physical, cardiac testing can be used to establish the diagnosis and determine the functional capability of the patient, the severity of the disease, and the category of risk into which the individual falls. With varying levels of detail and precision, diagnostic tests can establish or confirm the presence of blockages in the coronary arteries, the degree of blockages, damage to the heart muscle, enlargement of the heart chambers, congenital heart defects, abnormalities of the heart valves, and electrical disturbances that interfere with the rhythm of the heartbeat.

Thus, a major value of cardiac testing is its ability to increase the precision of the diagnosis, enabling today's physician to prescribe the treatment with the greatest likelihood of success for each individual patient. In many situations, judiciously ordered tests may also be used to uncover a cardiac abnormality even when there are no signs or symptoms.

The choice of tests and the order in which they are used is guided by the findings of the history and physical and by the physician's clinical judgment. For example, if a patient's symptoms are similar to those of congestive heart failure, the physician will recognize that heart failure is associated with poor heart muscle function and that a radioisotope study is an excellent method of evaluating the degree of heart muscle damage. If the patient has a heart murmur, the physician will suspect a lesion of a heart valve; in this case, echocardiography is warranted because it allows the physician to see the valve actually functioning.

In general, the diagnosis of heart disease progresses in a stepwise fashion from the simplest, least invasive, least expensive, and least risky method. As more information about a patient's condition is accumulated, appropriate decisions can be made regarding the use of more sophisticated and more invasive diagnostic procedures. The following sections describe each of these tests in detail and generally in the order in which they might be ordered—though not all of them would be used in any one patient. Many patients with heart disease may require only one, or at most two, tests to make an accurate diagnosis. (The role of these diagnostic procedures is also discussed in individual chapters on specific types of heart disease.)

THE GENERAL EXAM

THE ELECTROCARDIOGRAM

The electrocardiogram (ECG) is one of the simplest and most routine tests used by cardiologists. It is often the first test used to follow up the medical history and physical exam. Millions of ECGs are now performed each year in doctors' offices and in hospitals because the test is noninvasive, does not entail any risk to the patient, and yields valuable information about a wide variety of heart conditions. (See box, "Electrocardiogram.")

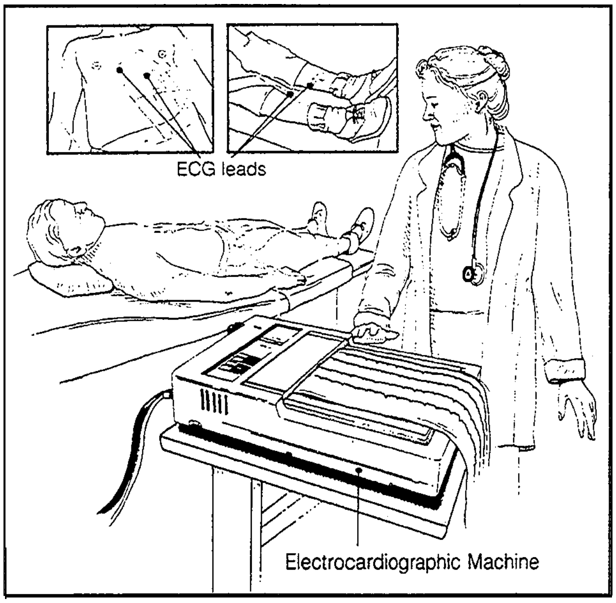


Figure 10.1
An electrocardiogram (ECG) records the heart's electrical activity through electrodes, or leads, attached to the chest or ankles. The impulses are transmitted to a machine with special needles that move over a continuous strip of paper, recording the results.

The primary purpose of the ECG is to yield information about heart rhythms and electrical configurations that may provide clues to a heart problem or heart attack, Irregular heartbeats, or arrhythmias, are a major factor leading to sudden death, which accounts for about 60 percent of heart attack deaths in this country. (See Chapter 11.)

Electrocardiogram

Description
Electrode leads are attached to the patient's arms, legs, and chest, and, while the patient lies still, they measure and record the electrical activity of the heart, which is printed out in the form of a series of waves representing each heartbeat.

Major Uses
Provides initial evaluation of patient with suspected heart disease
Can usually detect the presence of heart attack, old or current
Detects and defines disturbances in heart rhythm
Detects wall thickening (hypertrophy)

Advantages
Totally noninvasive and safe
Can be obtained quickly and easily
Relatively low cost

Disadvantages
Often nonspecific
May not always be sufficiently precise for detailed diagnosis

Availability
Readily available in all health care facilities and virtually all cardiologists' and internists' offices

Normally, the heartbeat originates from a specialized group of cells in the right atrium. These cells are technically called the sinoatrial node, but are more commonly referred to as the hearts natural "pacemaker." The electrical signal, which makes the heart muscle contract and pump blood, travels from the pacemaker through the left and right atria to the atrioventricular (AV) node. The AV node then directs the signal through fibers in the ventricles.

Damage to the heart muscle in the area of the pacemaker, the AV node, or anywhere along the electrical signal's pathway can lead to an abnormal rhythm. An ECG also can reveal evidence of muscle damage from a previous heart attack, enlargement (hypertrophy) of the heart, and a variety of conduction disturbances. The particular findings will determine the type of interim treatment that may be needed and indicate which, if any, additional tests should be ordered next.

The electrical activity of the heart is monitored through a series of electrical leads placed on each limb and across the chest. (See Figure 10.1.) These leads act as sensors for the electrical pathway in the heart muscle. The results are printed out on a strip of paper in the form of continuous wavy lines, representing outputs from combinations of 12 leads. (See

Figure 10.2.) The configuration of these waves may provide important information concerning the nature of the individual's cardiac problem.

Each wave on the printout of the ECG is broken into segments designated by the letters P, Q, R, S, and T. Each segment represents a different stage of the contraction and relaxation of the heart muscle, corresponding to the emptying and filling of blood in the atria and ventricles. The beginning of the heartbeat, in which stage the right atrium contracts, is designated by the P wave. The QRS segments of the wave represent the contraction of the ventricles. The T wave represents the depolarization of the electrical current and the end of one heartbeat (relaxation phase of the heart cycle). Studies have shown that a flattening or depression of the normal configuration of the ST segment is an important indicator of permanent or temporary damage to the heart muscle caused by lack of oxygen.

Two examples of results of an ECG illustrate the rational ordering of tests: The presence of ST segment depression on an ECG in a patient with symptoms of coronary artery disease may indicate the need for an exercise stress test to learn more about the extent of ischemic disease and whether it is due to blockages in the coronary arteries. The finding of increased voltage on the ECG might indicate excessive heart-wall thickening (known as hypertrophy) and indicate the need for an echocardiogram to measure heart-wall thickness and function.

No special preparation is necessary for an electrocardiogram. The patient will be asked to remove clothing above the waist. While he or she lies down, a gel-like paste will be applied to areas of the upper arms, chest, and legs so that cloth patches attached to the ECG leads can be affixed. The test generally lasts about five minutes.

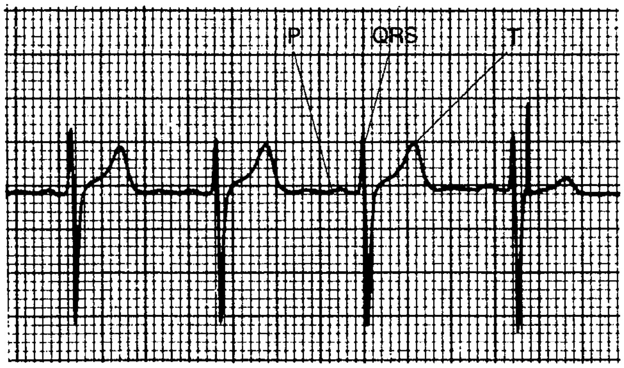


Figure 10.2
This is a normal electrocardiogram (ECG) with the P wave representing contractions of the atria, the QRS segment representing contractions of the ventricles, and the T *wave* representing the return of the electrical impulses to zero.

Signal-Averaged Electrocardiogram

A still investigational form of electrocardiographic testing is the signal-averaged electrocardiogram (SAECG), or late potential study. This test picks up small currents that are present in the electrical pathway long after normal muscle activation. These currents, called late electrical potentials, are generally found in areas of injury. For this test, a regular electrocardiogram is taken, but for a longer period of time (perhaps up to 30 minutes). A computer is used to superimpose the resulting signals on top of each other and create an averaged ECG which is then analyzed to detect late potentials. The presence of these late potentials indicates a propensity for developing heart rhythm disturbances. (See Chapter 16.) This test is one way of evaluating individuals suspected of having certain types of rhythm abnormalities.

CHEST X-RAY

A second routine test often used initially after the medical history and physical examination is the chest X-ray. Approximately 750,000 chest X-rays are performed by cardiologists each year. The small amount of radiation involved in the exposure from a single X-ray is minimal and should not be of concern to the patient. There are no other risks involved in X-rays; they are painless, fast, and relatively inexpensive.

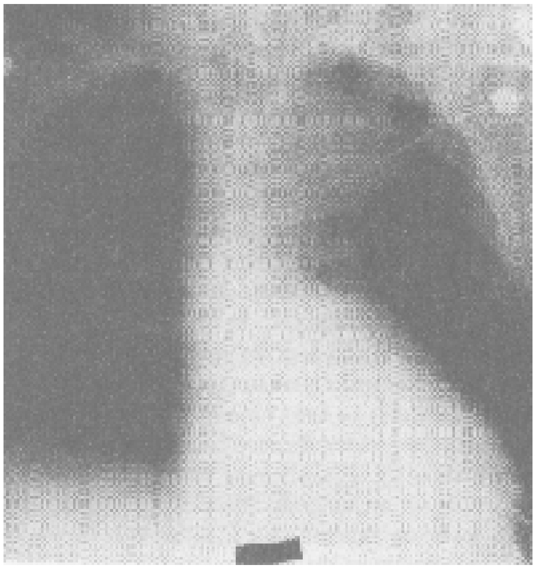


Figure 10.3
Chest X-ray in a patient with Marfan syndrome and an aortic aneurysm. There is a large outpouching of the *aorta noted* in the upper right-hand corner. This is *an* aneurysm characteristic of this disorder.

The main advantages of the chest X-ray are in differentiating primary lung disease from heart disease and in providing a clear view of anatomical abnormalities such as heart enlargement or congenital defects.

Generally, the chest X-ray is used to define enlargement of the heart or pulmonary vessels; detect the presence of calcium deposits, which may indicate muscle scarring or blockages in the arteries; show any dilation of the aorta (expansion may be due to Marfan's syndrome or aortic aneurysm); and indicate the presence of fluid in the lungs when congestive heart failure is suspected. (See Figure 10.3.)

HOLTER MONITORING

In some cases, a physician may want to know what happens to an individual's heart rate over a longer period of time than can be measured with an electrocardiogram in a single office visit. The Helter monitor provides a means of recording an ECG continuously on a small cassette tape, usually for 24 hours, while the patient goes through normal daily activities. Potentially serious arrhythmias are the primary indication for using a Helter monitor, although it is increasingly used in the diagnosis of silent ischemia. (See box, "Helter Monitor.")

Holter Monitor

Description

Uses a portable recording device, worn by patient under clothing and attached to the chest via electrode leads and patches, to record an electrocardiogram continuously over an extended period, usually 24 hours.

Major Uses

Documents and classifies arrhythmias
Assesses results of antiarrhythmia medications, cardioversion, or ablation
Diagnoses "silent" ischemia

Advantages

Produces "hard-copy" graph of abnormalities
Noninvasive
Very reliable
Allows assessment during patient's typical daily activities

Disadvantages

No identification or warning of serious arrhythmia as it occurs
May often require more than 24 hours to detect an event

Availability

Almost all hospitals, as well as many cardiologists' offices

A patient undergoing a Helter monitor test will be asked to wear a small cassette recorder on a shoulder strap or belt. (See Figure 10.4.) The continuous ECG reading is produced via several electrical leads from the recorder that are attached to the patient's chest under the clothing. Information on the heart rate is recorded on a cassette tape, which later will be played back through a computer, analyzed, and printed out in the same manner as a standard ECG.

The data will indicate at which point or points during the recording period the patient experienced abnormal heart rhythms. Some devices allow the patient to insert markers into the recording to indicate the time of day any symptoms were felt. The patient is often asked to keep a diary to note the type of activity in which he or she was engaged when the arrhythmia occurred.

If rhythm disturbances are serious enough to warrant treatment with an antiarrhythmic drug, the Holter monitor may be used for a longer period of time to determine whether the medication is effective. This information is crucial because the effectiveness of a particular drug and the effective dose may vary widely among patients. (See Chapter 16.)

The Helter monitor also has the capability of demonstrating the presence of myocardial ischemia via ST segment depression. For this reason, Holter monitoring has become a potentially important new tool for detecting "silent ischemia" during routine activities of everyday life.

There are a variety of Helter monitors in use. Some record continuously, while others begin recording only when the patient senses a rhythm disturbance and activates the device. Some newer models are programmed to sense abnormalities and begin recording automatically.

Although all of the various Helter monitors are effective, none is free from error, which most commonly is the false appearance of tachycardia. Usually recording errors are due to a loose electrode or to the patient's inadvertently scratching an electrode. But errors also may occur when batteries are low or when a previously used tape has not been completely erased. While false readings may result in an inaccurate diagnosis, this outcome is uncommon.

Helter monitoring involves no risk or discomfort. There is no special preparation for the test, although men may need to have small areas of the chest shaved. Patients can carry on their normal daily activities, although they must avoid showering.

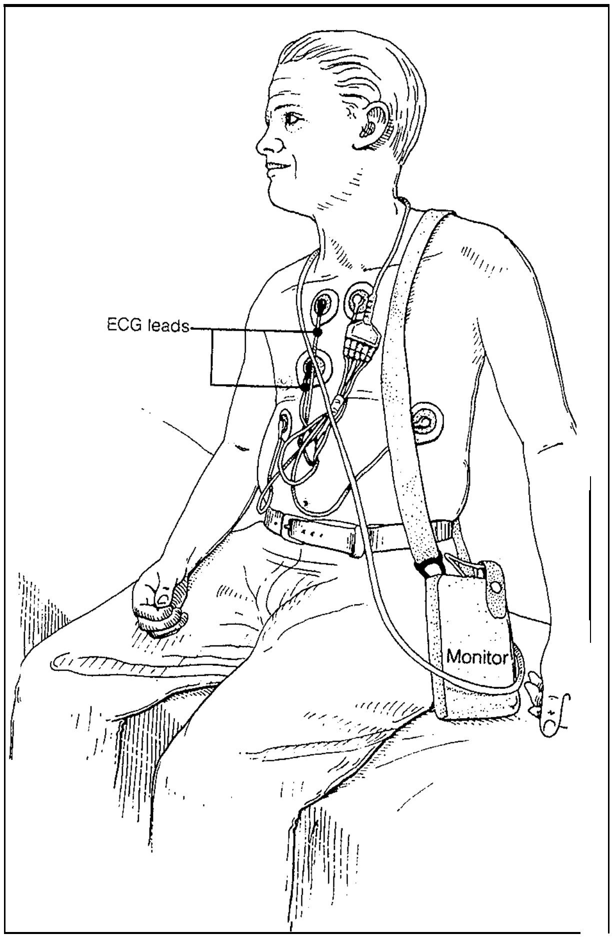


Figure 10.4
For *an ambulatory electrocardiogram (ECG), also called* Helter *monitoring, a person wears a shoulder harness holding a portable tape recorder connected to electrodes attached to the chest. It is worn, usually for a 24-hour period of time, under clothing, and the person is monitored* while going about his or *her normal activities.*

ECHOCARDIOGRAPHY

Echocardiography is one of the most important noninvasive techniques used in the diagnosis of heart disease today. Approximately 970,000 echocardiograms are performed each year.

Echocardiograms are obtained by reflecting high-frequency sound waves off various structures of the heart, then translating the reflected waves into one- and two-dimensional images. New experimental techniques are also producing finely detailed three-dimensional images of the heart's anatomy. (See box, "Echocardiography.")

The advantages of echocardiography over other diagnostic techniques are many. It is painless, risk-free, and ideal for diagnosing problems in children and pregnant women for whom X-rays would be inappropriate, and it requires no preparation of the patient. Echocardiography is most commonly used for diagnosing conditions that require knowledge of the anatomy of the heart, such as valve disease, ventricular enlargement, and congenital heart abnormalities. It is widely employed in the diagnosis of pericardial effusion (fluid around the heart) and is the best technique for diagnosing idiopathic hypertrophic subaortic stenosis, a relatively common condition in which a portion of heart muscle has become excessively thickened,

Echocardiography also is the preferred method for identifying intracardiac masses such as tumors and blood clots. It can be used to monitor the effectiveness of treatment for high blood pressure by taking periodic measurements of the size of the left ventricle and the thickness of its wall. Recent studies have shown that left ventricular enlargement diminishes with effective hypertension treatment.

Echocardiography

Description

Patient sits or lies down while technician holds a transducer—a small device that both emits and records sound waves—against the chest in order to produce different views of the heart in motion.

Major Uses

Measures heart size, function, and thickness of muscle

When combined with the Doppler technique, measures blood flow through heart chambers, as well as flow through and pressure gradients across valves to determine the degree of narrowing, regurgitation, or calcification

When combined with stress test, evaluates wall motion of ventricles and other physical characteristics of the heart under stress

Identifies tumors or clots within heart

Detects congenital abnormalities

Advantages

No pain or risk

Noninvasive

Reduces need for cardiac catheterization

Very reliable

Disadvantages

Cannot measure ejection fraction as precisely as MUGA

Good images cannot be obtained in 5% to 15% of patients, especially those who have broad chests or are obese

Availability

Most medium-sized hospitals and all large medical centers, many cardiologists' offices

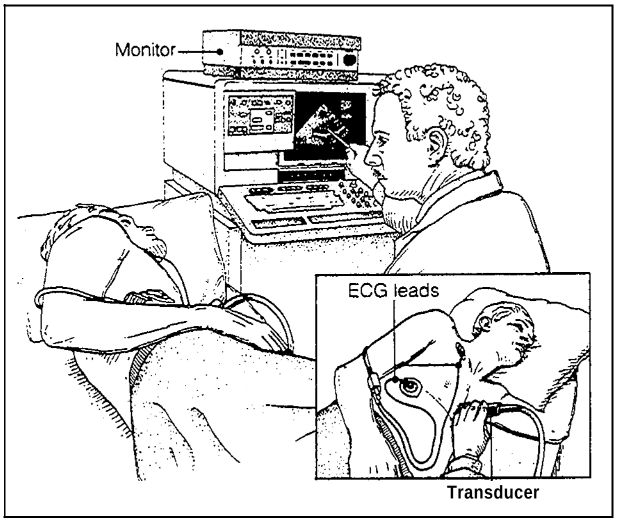


Figure 10.5
An *echocardiogram uses sound waves, emitted and received by a microphone-)ike device called a transducer, to examine the heart. The results are translated into a* picture *on a television screen.*

When combined with the Doppler technique, which records changes infrequency of sound waves, echocardiography can be used to measure blood flow through heart valves and calculate pressure differences across valves. Doppler echocardiograms are the best way to determine the degree of narrowing, calcification, or leakage of a valve. The technique also provides measurements of blood flow within the heart's chambers to assess their function while pumping and resting (systolic and diastolic function), and blood flow in the major blood vessels and peripheral vessels in the arms and legs.

Echocardiography techniques also are being applied to exercise testing so that the motion of the walls of the ventricles and other physical characteristics of the heart under stress can be studied. A stress echocardiogram is done immediately following an exercise stress test or after the injection of the drug dobutamine, which produces a stress on the heart similar to exercise. Failure of a part of the heart to contract well often indicates that under conditions of stress, part of the heart does not receive enough blood and is supplied by a narrowed coronary artery.

The recent development of transesophageal echocardiography, a procedure in which the sonar device is attached to a relatively long, narrow tube and inserted into the esophagus, permits physicians to monitor heart function during surgery more closely. This is more complicated and slightly riskier than routine echocardiography.

No special preparation is necessary for this test. It can be performed in a hospital outpatient department or at a patient's bedside and is available in some cardiologists' offices. (See Figure 10.5.) A colorless gel is applied to the patient's chest and a transducer—a small device that both emits and records sound waves—is held against the chest in various locations to produce different views of the heart. The test takes from 10 to 30 minutes, depending on the number of views and whether the Doppler technique is used.

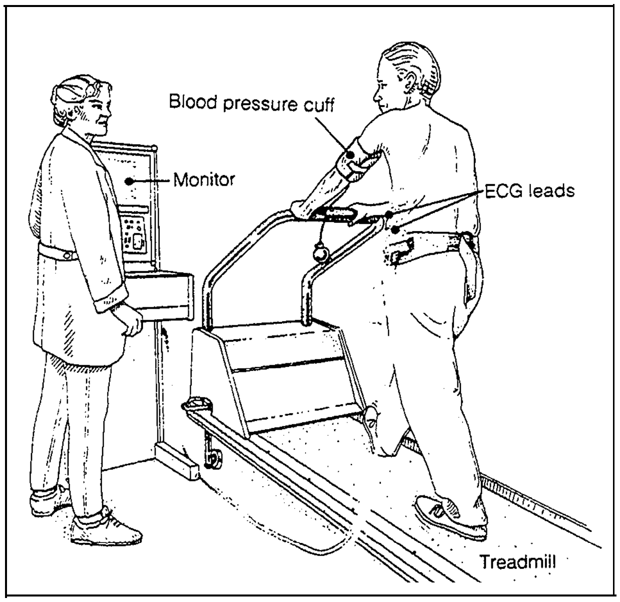
EXERCISE STRESS TESTING

The exercise stress test, sometimes referred to as a treadmill test, is essentially an electrocardiogram taken while an individual walks on a treadmill or pedals a stationary bicycle. (See Figure 10.6.) It is used to determine the functional capability of the heart, or in other words, its level of fitness. (See box, "Stress Test.")

As the name "exercise stress test" implies, the patient is exercised in order to create a greater level of work, or stress, for the heart. Exercise testing can reproduce symptoms, such as chest pain (angina pectoris), that a patient may encounter during physical exertion in the course of everyday activities. It allows a physician to determine the amount of exertion under which the patient experiences chest pain, while monitoring specific functions of the heart-primarily the heart rate and blood pressure.

A stress testis usually sustained until pain is provoked, significant changes in the electrocardiogram

Figure 10.6
An exercise *electrocardiogram (ECG) is usually performed using a treadmill or stationary bicycle. The test measures the capacity of the heart at* work.



Stress Test (Exercise Stress Test)

Description

Individual walks on treadmill or pedals exercise bicycle at increasingly higher levels of exertion while heart rate and rhythm, blood pressure, and, sometimes, oxygen consumption are monitored.

Major Uses

Evaluates chest pain
Establishes severity of coronary disease
Screens people at high risk of coronary disease
Checks effectiveness of antianginal drugs
Screens older adults (especially males) before they begin strenuous exercise or activity programs

Advantages

Very high safety rate
Identifies cardiac problems that do not show up at rest or with moderate activity
Reliable results
Noninvasive
Simulates stress to heart in everyday activity
Not difficult to perform or repeat
Less expensive than isotope (thallium) stress tests

Disadvantages

Generally cannot be used on patients with abnormal resting ECG
Relatively high false positive rate (15%–40%), especially in young women who have no symptoms of coronary disease
Relatively high false negative rate (15%–30%), especially in men
Can only be used with individuals capable of strenuous exercise on a treadmill or exercise bicycle

Availability

Readily available at hospitals, many cardiologists' offices, and exercise training facilities

(ECG) occur, or a target heart rate is achieved. These changes or symptoms will not usually occur during a traditional, resting ECG. The ECG component of the stress test allows for the detection of an abnormality even if pain is not provoked. Electrocardiogram abnormalities are thus a fundamental part of the diagnostic capabilities of the exercise test.

The exercise stress test may reveal the presence of myocardial ischemia (inadequate blood flow to the heart), left ventricular dysfunction (decreased pumping ability), or ventricular ectopic activity (heart rhythm abnormalities originating in the ventricle). It also provides information on the relationships among these findings.

The most common indication for an exercise stress test is the evaluation of chest pain, which mayor may not be angina pectoris. Angina occurs when the heart's demand for blood and oxygen exceeds its supply, a condition known as myocardial ischemia. Blockages in the coronary arteries are the main cause of ischemia, but angina usually will not occur at rest unless the blockages are extremely severe. The rate at which the heart's demand for blood and oxygen exceeds the supply during an exercise test generally reveals the severity of the disease. If angina occurs rapidly with little exertion, the blockages are likely to be extensive and the chance of a future heart attack significant.

The stress test is often used to determine the level of heart function and prognosis in a patient with established ischemic heart disease, particularly after he or she has had a heart attack and has been stabilized. It is also a source of clues about the cause of angina that is not easily controlled with medication, and a way of measuring heart function following balloon angioplasty or coronary artery bypass surgery. In nonacute settings, it is widely used to monitor the progress over time of treatments such as angioplasty, bypass surgery, medication, and life-style changes.

Less frequently, exercise testing may be part of a physical examination for healthy, middle-aged individuals who do not have symptoms of heart disease. In this case, it is used to establish cardiac fitness for certain occupations (such as piloting commercial aircraft), or when such individuals have been sedentary and want to start a program of vigorous exercise, such as jogging.

For reasons not completely understood, stress tests are less accurate in young women without symptoms than in men without symptoms. Because the rate of false positives (an indication that heart disease is present when it is not) is higher in these asymptomatic women, stress tests are generally not recommended unless heart disease is strongly suspected.

In the past few years, exercise stress testing has become an important tool for diagnosing a condition known as "silent" ischemia, which means ischemia without chest pain. During that time, cardiologists have come to realize that the majority of ischemic episodes are silent—as many as 75 percent, according to some studies.

Silent ischemia is often detected in unsuspecting individuals when exercise stress testing is performed as part of a routine physical. However, there is currently much debate over whether the general public should be screened for ischemia via exercise stress testing. Because stress testing is relatively expensive, widespread screening for low-risk populations is not likely to be recommended in the near future. Still, individuals who have a family history of heart disease, or major risk factors, might consult their doctors about exercise stress testing, even if they have no symptoms.

The goal of the stress test is to reproduce symptoms or the appropriate physical state within the first 6 to 15 minutes of physical exertion. This goal is achieved by periodically increasing the speed and incline of the treadmill or the resistance of the pedals on an ergometer (stationary bicycle). A briefer test may not provide enough exertion to reproduce symptoms, while a longer, less rigorous one may tire a patient before symptoms can occur.

The heart's specific level of function is graded using a scale of metabolic equivalents (METs), which represent the workload on the heart during the exercise test. One MET is the amount of energy expended while standing at rest. The patients score will be determined by the number of METs required to provoke symptoms.

More than a million stress tests are performed each year, with a very low risk of complications. The chance of a nonfatal heart attack occurring during an exercise testis about 1 in 100,000. The risk of complications is presumably highest in patients with severe heart disease.

There is no special preparation for a stress test. Individuals scheduled for this test may be advised to have only alight breakfast or lunch at least two hours before the test, in order to minimize any possibility of nausea that might be brought on by heavy exercise. They are also advised to wear rubber-soled shoes and loose, comfortable clothing, such as shorts or sweatpants and a T-shirt. In order to be sure that the ECG electrodes stay in place, men may need to have small areas of the chest shaved. For the same reason, both men and women are advised not to use body lotion.

The stress test begins and ends with a regular (resting) ECG (see earlier discussion of the electrocardiogram), and blood pressure is taken periodically. The entire test takes about 30 to 40 minutes, with the treadmill or ergometer portion lasting no more than 15 minutes.

NUCLEAR CARDIOLOGY

The use of radioactive substances to learn about the function of the heart was first suggested as early as 1927. Scientists at that time discovered that they could inject a radioisotope into the blood via a vein in one arm and, using a simple radiation detector, track its arrival in the other arm a short time later.

Today, nuclear cardiology has become a sophisticated, essentially noninvasive method of evaluating heart disease. Nuclear studies may be ordered early in the diagnostic process, before heart disease has been clearly established, or used to evaluate heart function following a heart attack or other major cardiac event.

The results of nuclear studies will determine whether further testing is necessary and, if so, what type. If the results indicate that ischemia is present and is due to blockages in the coronary arteries, angiography, a type of cardiac catheterization (discussed later in this chapter), will be seriously considered.

Although the term "nuclear" sometimes frightens patients, these procedures pose no danger. The radioisotopes used inmost studies contain only a minute amount of radiation, remain in the body for a short period of time (usually four to six hours), and are well tolerated by patients. The procedures entail an extremely low risk for adults. Fetuses, however, have a lower tolerance of radiation, so such tests are inappropriate for pregnant women and nursing mothers.

Although nuclear technology has evolved only in the past 30 years, the basic principle is the same as envisioned in 1927: A small amount of a short-lived radioisotope is injected into the bloodstream; then a radiation-detecting device is used to follow its progress and specific uptake through the circulatory system.

In nuclear cardiology procedures, a scintillation camera (see Figure 10.7), also called a gamma camera, is used to detect the radiation (gamma rays) emitted by the isotope; a computer then collects and processes the data, quantifying the information and displaying it as still pictures of the heart. Three-dimensional images, or tomographs, can be obtained by taking multiple pictures from a variety of angles in a single plane. The computer processes this information and develops a three-dimensional reconstruction.

MAJOR USES

Nuclear cardiology has two primary functions: assessing the performance of the heart, and studying its viability and metabolism and the flow of blood into the heart muscle. Such testing is probably the most precise means currently available to detect the pres-

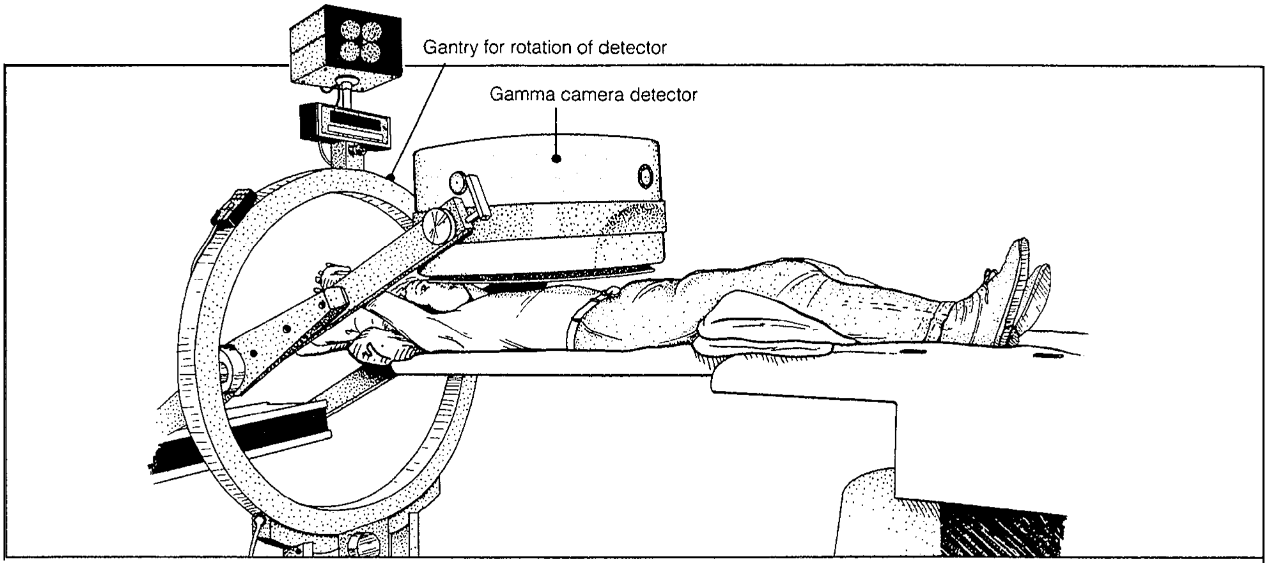


Figure 10.7
A thallium scan begins with an intravenous injection of the isotope thallium. This accumulates in the normal heart muscle and is visible on a picture made with a gamma camera. In this illustration, the camera is capable of rotating around the patient so that three-dimensional tomography (SPECT) can also be obtained.

ence of ischemic damage to the myocardium (heart muscle) and to demonstrate how well the heart's ventricles are functioning. Because of the accuracy and relative ease of testing, nuclear studies are increasingly used in major hospitals to measure this ventricular function immediately following treatment of a heart attack with a thrombolytic (clot-dissolving) drug.

The two major functions of nuclear testing are accomplished by using two general types of radioisotopes. For measuring the heart's performance, the isotope used most often is technetium-99m. This isotope stays in the bloodstream as the blood circulates through the heart, allowing the technician to see the volume of blood being pumped from the ventricles and the flow of the blood through the valves. To study the heart muscle itself, the most commonly used isotope is thallium-201, which is taken up by heart muscle from the bloodstream. The resulting pictures show a contrast between areas of the heart muscle that are functioning normally and receive an adequate blood supply and those that are damaged and thus do not receive an adequate supply. Studies using thallium-201 are known as perfusion imaging and are currently the most widely used tests in nuclear cardiology.

EQUILIBRIUM RADIONUCLIDE ANGIOCARDIOGRAM (MUGA SCAN)

The test most commonly used to assess heart function or performance is the equilibrium radionuclide angiogram, more commonly known as the MUGA (mul tigated graft acquisition) test or MUGA scan. For this test, the patient is injected with the technetium isotope, which remains in the blood for several hours. Gamma rays are detected and ECG information accumulated over the course of several hundred heartbeats. This information is analyzed by a computer, which summarizes it and generates a moving picture of the beating heart. (See box, "MUGA Scan.")

The MUGA test reveals information about the functioning of the left ventricle, the hearts main pump. The information of greatest interest is the ejection fraction, which is the amount of blood squeezed from the left ventricle with each heartbeat. Within limits, the greater the ejection fraction, the greater the likelihood that the patient has a normal heart. A low ejection fraction will indicate a weakened ventricle, which may be due to blockages in the arteries that supply the heart muscle, to valve defects, or to a primary problem with the heart muscle itself. The ejection fraction of the right ventricle can also be measured. Damage to the right ventricle may indicate the presence of chronic lung disease, usually acquired pulmonary hypertension.

Other uses of performance testing include the diagnosis of congenital heart disease and the assessment of surgery to repair a congenital defect. It is also beneficial in the diagnosis of valvular heart disease, either at rest or combined with an exercise test. Within this context, a normal ejection fraction may indicate the presence of a primary valve disease that is amenable to surgical replacement. However, poor

MUGA Scan (Equilibrium Radionuclide Angiocardiogram)

Description

After receiving a small injection of a radioisotope, the individual lies on a table while a scintillation camera records images (linked to the electrocardiogram) of various parts of the heart in motion.

Major Uses

Evaluates cardiac function
Measures the ejection fraction (how much blood is pumped from the left ventricle with each heartbeat)
Shows how different regions of the heart are contracting

Advantages

Relatively noninvasive
Gives the most accurate measurement of heart function, namely ejection fraction
Produces reliable results that can be repeated without difficulty

Disadvantages

Requires the injection of a small amount of radioisotope
May not be possible to obtain the most accurate information if there is a very irregular heart rhythm

Availability

Readily available at hospitals, noninvasive laboratories, and in a limited number of doctors' offices

ejection fraction in the presence of a valve problem is more likely to indicate primary disease of the heart muscle, or valve disease that has progressed beyond the point of surgical repair.

More recently, cardiologists have learned that the MUGA scan is quite useful for monitoring the diastolic function of the heart, or how the left ventricle fills with blood between heartbeats. A substantial number of elderly patients with coronary artery disease or congestive heart failure can have a normal ejection fraction and normal squeezing, or pumping, of the ventricle, but have poor diastolic function (abnormal filling of the ventricle because of increased stiffness). This monitoring ability has important implications for the treatment of people with congestive heart failure because of poor filling, a condition managed quite differently from routine heart failure, in which the problem is poor pumping rather than poor filling.

No special preparation is needed for this test, which is usually done on an outpatient basis in a hospital or independent laboratory. Discomfort, if any, is momentary, during the injection of the isotope. The patient then lies on a table while scanning pictures are taken, a process that can last from 10 to 15 minutes, depending on the information sought. The only risk, which is extremely low, is from the exposure to the radioisotope.

VEST SCAN

One of the newest applications of radioisotopes in heart performance studies is ambulatory monitoring using a miniaturized radionuclide detector, called a VEST, that is worn by the patient. The technique may be used to monitor patients with unstable coronary syndromes or to monitor heart function prior to hospital discharge in people who have undergone thrombolysis for a heart attack. The test procedure is the same as for the MUGA scan, except that the patient wears the miniaturized equipment for about four to six hours and can move around freely during that time.

PERFUSION (BLOOD FLOW) IMAGING

In perfusion imaging, a radioisotope is injected into the bloodstream and absorbed by the heart muscle as it passes through the heart's chambers. The basic principle is that healthy heart muscle cells will absorb the isotope almost immediately; those that are transiently ischemic (not receiving an adequate blood supply) will take longer to absorb it, and those that have been permanently scarred by a heart attack will not absorb the isotope at all. Thus, by comparing two or even three sets of pictures taken over time, the cardiologist can make an accurate assessment of heart muscle damage.

Test results that are normal indicate an extremely low risk of a coronary event in the following year, while positive results will identify a majority of patients who are at high risk. Absorption by the lungs of a lot of the isotope is an indication of poor heart function during exercise and is a poor prognostic sign.

THALLIUM STRESS TEST (THALLIUM SCAN)

Perfusion imaging is used in combination with an exercise stress test or, for patients who cannot tolerate exercise, with a drug that produces the same effect. For patients who have heart disease or are strongly suspected of having it, the thallium stress test more accurately defines the extent of existing damage and much more sensitively predicts future heart attacks than standard ECG exercise testing or chest pain alone. The number of cases of heart disease detected with thallium scans is about 20 percent greater than it would be with exercise testing alone. (See box, "Thallium Stress Test.")

The thallium stress test begins in the same way as a regular stress test, with a resting ECG, regular blood pressure monitoring, and exercising with gradually increased speed or resistance on the treadmill or bicycle ergometer. An intravenous infusion of sugar water is started in advance. When the individual has exercised to peak exertion, a very small amount of thallium is administered through the intravenous line, and then he or she continues to exercise for one minute more. After that point, exercise is stopped and the patient lies on a special table under a scanning camera. By this time the thallium has traveled throughout the body and is concentrated in the heart, where it is picked up by the camera in a series of pictures. This process takes approximately 20 to 45 minutes.

When a patient is too sick to tolerate, or is physically unsuited for, a treadmill or a stationary bicycle, dipyridamole (Persantine) or adenosine may be injected prior to the thallium.

Both drugs increase blood flow, thus producing the same cardiac effect without having the patient undergo physical exertion. Studies have shown that this technique is just as effective as exercise testing.

After the initial set of pictures, the individual will be asked to remain relatively quiet for two to three hours, during which time limited beverages, but not food, will be allowed. This period is followed by a second set of pictures, representing the heart in its resting state. In some cases, a third set of pictures is taken 24 hours later.

Thallium Stress Test (or Dipyridamole Thallium)

Description

After standard exercise stress test (see previous description), patient is injected with thallium radioisotope, then lies on a table while a gamma-detection camera is used to track uptake of the thallium in heart muscle; photos are repeated in 2-3 hours. Patients who cannot exercise are given the drug dipyridamole or adenosine to simulate effects of exercise.

Major Uses

Diagnosis of coronary disease
Determines extent of diagnosed coronary disease
Assesses effectiveness of angioplasty
Evaluates patients with abnormal ECG

Advantages

Measures the percentage of heart muscle not receiving adequate oxygen
Can identify problems with heart's blood supply during exercise in patients who have no ECG changes or symptoms
Low false positive and false negative rate
Identifies more cases of previously undetected heart disease than standard stress test
Dipyridamole or adenosine test can be done on patients who cannot exercise

Disadvantages

Time-consuming
Expensive
Requires IV injection of the radioisotope thallium

Availability

Most hospitals and many hospital outpatient facilities

OTHER ISOTOPE AND IMAGING TECHNIQUES

SINGLE PHOTON EMISSION COMPUTED TOMOGRAPHY

Thallium scans are usually done with a gamma detection camera, At many medical centers, a detection technique called single photon emission computed tomography, or SPECT, may be used to obtain three-dimensional thallium images of the heart. Although SPECT is slightly more expensive than standard nuclear imaging techniques, it may be superior in detecting individual lesions in the coronary arteries, in pinpointing the location of damaged and ischemic heart muscle, and in assessing the effects of treatment for ischemic heart disease. From the patient's point of view, the procedure itself is the same as that using the more traditional camera, only in this case, the camera rotates around the patient. In this way, it accumulates enough information to create three-dimensional images.

Relatively new nuclear imaging agents that may potentially replace thallium in standard techniques as well as SPECT are technetium-labeled isonitrile and teboroxime. Both agents are able to create much sharper images than thallium, and each has other unique advantages as well.

New monoclinal antibodies (cellular substances produced in laboratories through cloning techniques) that can target specific areas of the heart muscle have recently been developed. These antibodies are “tagged” with a radioisotope and tracked and imaged with highly advanced imaging techniques as they collect in the heart muscle. Still experimental, but with potential for clinical application in the near future, antibodies can define areas of the heart muscle that have been irreversibly damaged by a heart attack and cannot recover, even if blood flow is restored. This has important implications for treatment.

POSITRON EMISSION TOMOGRAPHY

A major research tool in the area of cardiac nuclear imaging is three-dimensional positron emission tomography (PET), which measures the metabolic activity of the heart, or, in other words, how the heart uses fuel, as well as blood flow (perfusion). Positron emission tomography is potentially important because it produces a very accurate definition of areas of the heart muscle that remain viable following myocardial infarction, But because PET is quite expensive and requires highly specialized equipment, it is not used routinely in the diagnosis of heart disease. In the near future, however, this important new technology may become more available clinically.

COMPUTED TOMOGRAPHY

Although computed tomography, commonly called CT scan, is often used in diagnosing stroke, its use in heart disease is generally reserved for diagnosing diseases of the aorta. The technique, from the patient’s point of view, is similar to other scans, but the scanning camera is rotated 360 degrees around the patient, who lies on a special table. New tomography techniques are being studied experimentally at this time and may be used clinically in the future.

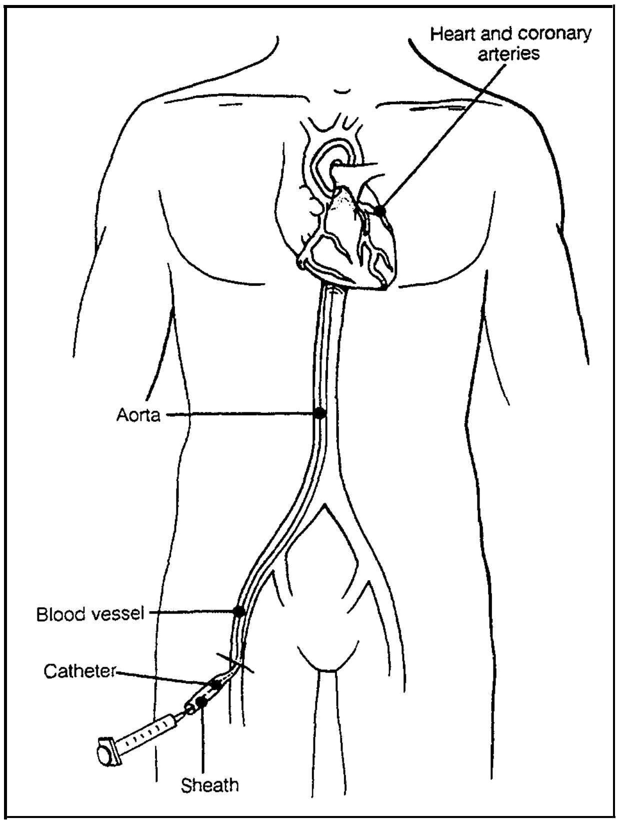
MAGNETIC RESONANCE IMAGING

Pictures of the heart in exquisite anatomic detail are possible with magnetic resonance imaging, or MRI. For now, expense and limited availability restrict the use of this sophisticated technique more to research, at least as far as heart disease is concerned. Further, it requires the patient to lie still in a small space for an extended period, making it impractical for patients who are acutely ill and difficult for people who are claustrophobic. In the future, however, MRI may become useful in a hospital setting for diagnosing various types of cardiac disease.

CARDIAC CATHETERIZATION

Cardiac catheterization is the process of inserting a thin, hollow tube into a blood vessel in the leg (or, rarely, the arm), then passing it into or around the

Figure 10.8
Cardiac catheterization performed from the leg near the groin. A small incision is made in the leg near the groin, and the catheter is inserted through a sheath into a blood vessel and carefully threaded up the aorta and into and around the heart.



heart in order to obtain information about cardiovascular anatomy and function. (See Figure 10.8.) First attempted experimentally on humans in 1929, cardiac catheterization evolved into wide clinical use in the 1940s. It is most commonly employed for evaluating disease of the coronary arteries, as well as valvular, congenital, and primary myocardial diseases. More than 900,000 cardiac catheterization procedures are performed in hospitals each year, making it one of the most widely used advanced diagnostic tests.

Catheterization of the coronary arteries, called coronary arteriography, is considered the "gold standard" against which all other methods of diagnosing coronary artery disease are compared. The findings from coronary artery catheterization are almost always compared with the findings from nuclear studies and exercise stress tests. In this manner, the important correlation is made between the anatomic site of the problem and its clinical and physiologic consequences.

Cardiac catheterization has three main uses, the first two being routine with all catheter procedures:

- The measurement of heart function by taking pressure readings around valves and within ventricles, arteries, and veins, using special catheters.
- The visualization of the ventricles, coronary arteries, and other vessels following injection of radiopaque contrast dye, which is used to produce X-ray movies called cineoangiograms or, simply, angiograms. The procedure itself is known as angiography.
- The biopsy of heart muscle via the insertion of biopsy instruments into the catheter. Microscopic examination of the biopsied tissue helps assess the possibilities of transplant rejection and diagnose heart muscle diseases and inflammatory heart diseases such as myocarditis. Biopsy is performed only if there are specific indications of disease.

Angiography is particularly useful for diagnosing congenital abnormalities, for examining overall patterns of contraction of the ventricles, and for identifying blood vessels anywhere in the body—but especially the coronary arteries—that are narrowed or obstructed. (See box, "Cardiac Catheterization and Coronary Angiography.")

Various methods of injecting the dye can provide different types of information. Dye can be injected and allowed to circulate through the vessels to produce a larger view of vascular and coronary anatomy, or it can be injected selectively at individual sites. For example, a simple way to demonstrate whether a valve is functioning is to inject dye from the tip of the catheter at a point just beyond the opening of the valve. If blood is being pumped through the valve normally, the dye will be pushed away by the force of the blood flow, revealing a characteristic pattern of dye removal. On the other hand, if there is valvular regurgitation-the backward flow of blood through a valve —the dye released in this area will move backward.

Coronary arteriography provides an anatomic map of the coronary arteries and a relatively clear picture of the location of blockages, their shape, and their degree of narrowing. From this information, a physician can also assess the volume of blood that is flowing through the coronary arteries and the degree of ischemia in the heart muscle.

Cardiac Catheterization and Coronary Angiography

Description

A small tube (catheter) is advanced into and around the heart through an artery or vein in the groin or arm in order to measure pressures within the heart and produce angiograms (moving X-rays) of the coronary arteries, left ventricle, and, where appropriate, other cardiac structures.

Major Uses

Evaluates individuals with chest pain or other cardiac disease
Defines function of the heart
Defines narrowing or leaking of the heart valves
Helps identify candidates for bypass surgery and angioplasty

Advantages

Provides precise anatomic information
Reliable

Disadvantages

Invasive procedure
Very small, but significant, risk of artery blockage at the site of catheter introduction, embolism, or heart attack

Availability

Readily available at mid-size hospitals and major medical centers and in a few free-standing (but usually hospital-affiliated) laboratories

During angiography, the physician may also catheterize the left ventricle and inject dye to determine the overall ventricular function, or make measurements of left ventricular pressure and directly view the contraction of the ventricle. Comparing information from the left ventricle (generally systolic and diastolic volume and the ejection fraction) will help identify areas of the heart muscle that may benefit from bypassing a blocked coronary artery.

Cardiac catheterization is usually performed as an inpatient procedure requiring a one-night hospital stay. In specific instances, the test may also be performed on an outpatient basis—the patient has the test in the morning and goes home in the early evening. In either case, the patient will be asked not to eat for at least six hours prior to the procedure and will be given a sedative for relaxation. The area where the catheter will be inserted, usually the groin, may be shaved. The procedure itself takes place in a catheterization laboratory, commonly referred to as a cath lab, where the patient will lie on a padded table under a fluoroscope (moving X-ray camera). The patient receives an injection of local anesthesia at the site of the incision, and an intravenous infusion (IV line) may be started.

To perform cardiac catheterization, the doctor inserts the catheter through a large-diameter needle and hollow sheath into an artery (to examine the left side of the heart) or a vein (to examine the right side of the heart). Using the fluoroscope for guidance, the doctor threads the catheter through the vein or artery into the heart, during which time the patient may feel some pressure, but no pain.

Once the catheter is in place, pressure readings (described above) may be taken in several locations and dye may be injected through the catheter. During the release of the dye, the patient may feel some nausea, hot flashes, and the need to urinate. These sensations generally pass quickly. At various times during the procedure, the patient may be asked to cough, pant, or breathe deeply. The procedure usually lasts one to two hours. Afterward, the patient is usually wheeled back to his or her room. The leg through which the procedure was performed is immobilized to ensure that there is no bleeding. This is usually done by placing a sandbag on the insertion site for 8 to 12 hours (or less for patients who are having an outpatient catheterization). If the procedure was performed through an incision in the arm stitches will be required and a splint may be used to immobilize the arm for 24 hours.

The patient may have solid food immediately if desired. He or she will be offered pain medication once the anesthesia wears off and will generally be discharged from the hospital the following morning.

RISK

In general, cardiac catheterization is considered to be a very safe procedure with little risk of complications. Nevertheless, an invasive procedure such as this has more potential for complications than the noninvasive procedures described earlier in this chapter. For this reason, most catheterization procedures are performed in a hospital or an outpatient center attached to a hospital so that rapid access to emergency services will be available should a serious complication such as a ruptured artery or embolism occur. In fact, the American College of Cardiology and the American Heart Association generally recommend against having cardiac catheterization done in an outpatient clinic that is not connected with a hospital. The primary factors that influence the risk are the level of experience of the team performing the procedure and the patient's general health and severity of heart disease. The risks of cardiac catheterization are divided into two types: those that can arise in the artery in which the catheter is inserted due to complications, and those that can occur in the arteries under study.

When local complications occur, they consist mainly of damage or bruising of the artery at the site where the catheter is inserted. The second group of complications are more serious and include the formation of blood clots, heart attack because of blocked blood flow to the heart by the catheter, sudden arrhythmias, stroke, and allergic reactions to the dye.

Discomfort may be unavoidable in some patients. About 10 percent develop nausea and vomiting immediately after the injection of contrast material, and a smaller percentage have allergic reactions to the dye, including headache, sneezing, chills, fever, hives, itching, or shock.

SUMMARY

Different types of cardiac testing can provide a large amount of information. In many cases, only one type of test may be necessary; in others, combining the results of two or more tests may yield greater precision in the diagnosis.

lt is important to understand that a patient who undergoes a large battery of tests is not necessarily receiving superior medical care, nor that care is substandard when relatively few tests have been ordered. The number and type of tests used will vary from patient to patient, depending on the type and severity of disease.

It is appropriate, however, for the patient as a consumer to ask the physician at any stage of the diagnosis why a particular test is being performed and what information the test is expected to yield. Cardiac testing should always flow in a rational order from the findings of the history and physical and from the results of each test used in the course of the diagnosis. This rational order of testing will minimize unnecessary costs and risks to the patient.