Evaluating Coronary Artery Disease

New England Nuclear

North Billerica, Massachusetts

The Continuing Education Committee

Technologist Section, Society of Nuclear Medicine

The Journal's continuing education series on nuclear cardiology is excerpted from New England Nuclear's technologist training manual,* Introduction to Nuclear Cardiology. *With NEN's permission, four of the eight chapters in the manual were selected for a four-part series in the JNMT. The Continuing Education Committee urges that a review of cardiac anatomy and physiology be completed in conjunction with this series of articles. This is the first of the nuclear cardiology series. The other chapters will be: An Introduction to Thallium-201, Acute Myocardial Infarct Imaging with Tc-99m-pyrophosphate, and An Introduction to Radionuclide Ventricular Function Studies. After reading and studying this article, the nuclear medicine technologist will be able to: (1) identify normal and abnormal components of an electrocardiogram, and (2) discuss the clinical utilities, basic methods, and possible complications of non-nuclear medicine procedures used to assess coronary artery disease.

This article will discuss some of the non-nuclear diagnostic procedures commonly used to evaluate coronary artery disease. Several of these tests may be used in conjunction with nuclear cardiology studies to better interpret the nuclear medicine findings. In some cases, the findings of the nuclear cardiology study will be used to interpret more specifically other diagnostic procedures. Non-nuclear medicine studies are used in conjunction with nuclear studies because they provide very different forms of information about heart disease. None of the procedures currently used to assess coronary artery disease will be directly replaced by nuclear studies.

Electrocardiography

The electrocardiogram (ECG) is simply a record of the voltage variations of the heart plotted against time.

The normal electrical pattern of the cardiac cycle is characterized by the waveform shown in Fig. 1. Each of the individual segments of the wave is designated by a letter (or letters), each representing a distinct activity during the cardiac cycle.

P Wave: The P wave represents the electrical activity associated with the original "pacemaking" impulse from the sinoatrial (SA) node and its subsequent spread through the atria. When P waves of normal size and shape are present, it can be assumed that the impulse began in the SA node; when P waves are absent or aberrant in size or shape, it implies that the impulse originated *outside* the SA node.

PR Interval: The period from the start of the P wave to the beginning of the QRS complex is called the PR interval. This interval represents the time taken for the original impulse to reach the ventricles and initiate ventricular depolarization. During this period, which normally does not exceed 0.20 sec, the impulse traverses the atria and the AV node. If the PR interval is prolonged beyond 0.20 sec, it may be assumed that a conduction delay exists in the AV node. In some cases the PR interval is usually short—less than 0.10 sec—implying that the current has reached the ventricle through a shorter-than-normal pathway.

QRS Complex: The QRS complex represents the depolarization of the ventricular muscle. Each QRS complex consists of an initial downward deflection (Q wave), a large upward deflection (R wave), and a second downward wave (S wave). Together, these waves reflect the time necessary for the impulse to spread through the bundle of His and its branches to complete ventricular activation. When the duration of this impulse is increased—it is normally less than 0.12 sec—it indicates that the ventricles have been stimulated in a delayed, abnormal manner. This condition is called a *bundle branch block*.

ST Segment: The ST segment represents the period between

Adapted from Introduction to Nuclear Cardiology: A Technologist Training Manual.

the completion of depolarization and the beginning of repolarization of the ventricular musculature. The ST segment may be elevated or depressed when there is injury to this muscle. Classically, downsloping ST-segment depression is considered "diagnostic" of ischemia.

Analyzing these wave forms and intervals offers the physician a great deal of indirect information about the heart. However, the ECG does not depict the actual physical state or functioning of the heart. An ECG may be quite normal in the presence of heart disease if the pathologic process does not disturb the heart's electrical system. The principal clinical value of the ECG is its use in the diagnosis of coronary artery disease and in the identification of abnormal rhythms.

The normal ECG consists of a repetitive series of P, Q, R, S, and T waves, which conform to established standards for size and shape, and occur 60 to 100 times each min. (Q waves are not always present in all leads.) This pattern is called normal sinus rhythm. When either the rate or the contour of any of the individual waves is abnormal, the disorder is called arrhythmia. In the strict sense, the term arrhythmia indicates absence of normal rhythm and might be restricted to this one type of disturbance. In practice, however, the term is used to describe all forms of heartbeat abnormality—including disturbances in rate, rhythm, and conduction.

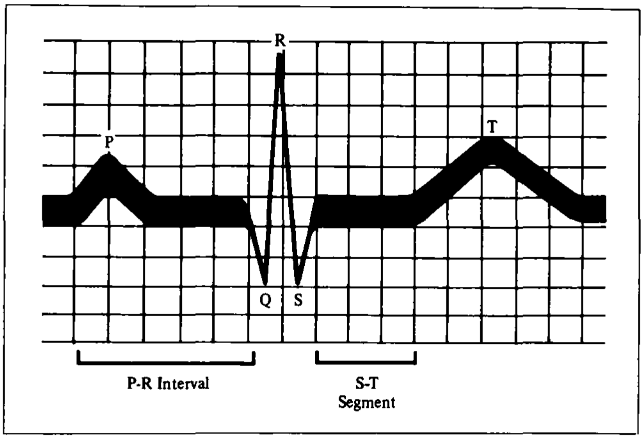

FIG. 1. Normal ECG shows pattern of P, Q, R, S, and T waves in cardiac cycle.

Stress Electrocardiography

Stress electrocardiography, or simply, exercise testing, is a useful and reliable noninvasive technique for evaluating cases of suspected or known coronary artery disease. Basically, the procedure combines electrocardiography with a graded exercise test to detect alterations in cardiac electrical patterns under conditions of stress that might signify myocardial ischemia.

Indications and Clinical Value: Because it is reasonably safe, easy to perform, and relatively inexpensive, exercise testing is an excellent screening procedure for identifying patients who have significant coronary disease. This procedure may establish or confirm the diagnosis of coronary disease in symptomatic patients (those with chest pain), when a carefully taken medical history, physical examination, resting ECG, and attempts at relieving pain with nitroglycerin have not confirmed the diagnosis.

For patients with known angina pectoris, exercise testing is useful as a means of assessing cardiovascular functional capacity, that is, the ability of the coronary arteries to deliver adequate quantities of oxygenated blood to the myocardium under the demands of stress. The test can demonstrate the level of physical exertion a patient can safely perform without symptoms or ECG changes, permitting the physician to establish meaningful guidelines for a patient for job-related tasks, recreational activities, or exercise programs. Exercise tests may also be extremely useful in detecting disturbances in cardiac rhythm induced by exertion, so that appropriate measures can be taken to prevent them. Finally, periodic exercise testing is useful in evaluating the response of a patient to conditioning or recuperation programs.

The indications for exercise testing are the same for patients with angina pectoris who have sustained myocardial infarctions and for those who have continued or recurrent angina pectoris following coronary artery bypass surgery. Most physicians recommend, however, that standard exercise testing not be performed for six weeks following acute myocardial infarction or coronary artery surgery although modified (limited) exercise tests may be performed earlier. Generally, exercise tests should not be performed soon after an episode of protracted anginal-type chest pain that may or may not be associated with transient ECG abnormalities.

Rationale and Procedure: Exercise electrocardiography attempts to evaluate indirectly the adequacy of coronary blood flow under conditions of maximal oxygen demand. It is assumed that an individual who can sustain maximal oxygen demand without demonstrating symptoms or ECG evidence of myocardial hypoxia must have normal, or essentially normal, coronary circulation.

As oxygen demand and consumption by the myocardium are increased during exercise, a corresponding increase in coronary blood flow should occur. The extraction of oxygen by the myocardium is already maximal at rest, so the increase in oxygen demand must be met primarily by an increase in coronary blood flow during exercise. An electrocardiogram recorded during exercise demonstrates the difference between oxygen demand (myocardial oxygen consumption) and oxygen supply (coronary blood flow), as manifested by characteristic "ischemia ECG changes," whether or not chest pain develops.

Equipment: During exercise electrocardiography, the patient may exercise in several ways. European physicians have traditionally used bicycle ergometers, while American cardiologists have favored treadmills. Several advantages may be cited for treadmill testing:

- ☐ It involves walking, a familiar type of exercise.
- ☐ It brings large muscle masses into play, eliminating localized areas of fatigue.
- ☐ It is the only method of exercise testing in which the rate of energy expenditure is involuntarily controlled.

The treadmill permits both speed and grade to be adjusted without disturbing the patient during the test. The ECG recording device contains both a strip chart recorder and an oscilloscope for continuous monitoring. A cardiac defibrillator is kept at hand, ready for immediate use, as are all drugs necessary for the treatment of any unexpected cardiac emergency. Although exercise testing can be performed safely in many locations, it is recommended that it be done only in a hospital or clinic setting, so that all medical facilities are immediately available should any untoward event occur. Fortunately, these events are rare, perhaps 1 in 10,000.

Preparation: The test is performed at least 2 to 4 hr after eating in order to avoid nausea, which may accompany vigorous exercise if food is taken shortly before the exercise period, and to avoid the appearance of ECG changes caused by indigestion. Medications that may affect either the response to or the interpretation of the test are discontinued at the appropriate time (Table 1) prior to the exercise if medically feasible. The patient is instructed to wear comfortable clothing and low-heeled shoes. Prior to the test, the patient must sign an informed consent form.

Monitoring: Exercise testing should be done only under the direct supervision of a trained physician, with continuous electrocardiographic monitoring and periodic blood pressure determinations. The standard 12-lead ECG is routinely recorded prior to exercise, in both the standing and supine positions, and in the standing position at the end of each stage of the exercise. The 12-lead ECG is used, instead of the common 3-lead ECG used in most office examinations, because it may demonstrate an ischemic response to exercise that might not otherwise be detected.

Performance: Following the resting electrocardiogram, the patient begins to exercise at progressively increased speeds and grades. The test is terminated when any of the following occur:

- □ typical anginal-type chest pain
- □ achievement of the target heart rate and its maintenance for at least 2 min, or exceeding the target heart rate by 8 beats/min.
- □ dizziness or light-headedness, or both
- □ shortness of breath or muscular fatigue to a degree that the patient is unable to continue.

Even in the absence of symptoms, the test should be terminated if

- □ frequent premature ventricular contractions or ventricular tachycardia are noted
- □ second-degree or complete AV heart block develops
- □ the systolic blood pressure exceeds 250 mm Hg or the diastolic blood pressure exceeds 135 mm Hg, or both
- □ supraventricular tachycardia is noted
- □ a diagnostic degree of ischemic ST depression or elevation is observed on the ECG
- □ the patient's ECG cannot for any reason be properly monitored during exercise.

Interpreting the Test: The ischemic ECG response to exercise can be seen during or after exercise. It may either precede or follow the development of chest pain and may even be seen in the absence of chest pain. An ischemic response to exercise is defined as a 1 mm or more, flat or downsloping ST-segment depression lasting 0.08 sec or more. A corresponding degree of ST-segment elevation is also classified as an ischemic response.

TABLE 1. Drugs That Can Affect the Response to and Interpretation of Exercise Tests

Drug	When to discontinue prior to test
Digitalis	1–2 weeks
Diuretics	4 days
Antihypertensives	4–7 days
Beta-adrenergic blocking agents	2 days
Antiarrhythmic agents	2 days
Tranquilizers and sedatives	1 day
Nitroglycerin	1 hour
Long-acting nitrates	1 day

Other findings suggestive of an ischemic response to exercise, but which must be evaluated acording to the clinical condition of the patient, are

- □ anginal-type chest pain in the absence of ST-segment changes
- □ premature ventricular contractions noted before, during, or after exercise
- □ development of ventricular tachycardia
- □ development of conduction disturbances of supraventricular tachyarrhythmias.

It is important to note that premature beats that tend to disappear with exercise may also indicate significant underlying coronary artery disease.

Although a positive response to exercise correlates well with the presence of significant coronary artery obstruction, particularly if two or more vessels are involved, the ischemic response to exercise is not specific for coronary artery disease. It may be seen in patients with other types of heart disease, such as left ventricular hypertrophy or aortic stenosis, where there is decreased tolerance of oxygen deficit. A positive response may also be seen occasionally in healthy people, notably women, whose arteriograms show normal coronary arteries.

On the other hand, patients with significant coronary artery obstruction may have a normal response to an exercise test. Such results are most often obtained from patients with single-vessel disease who are unable to attain the target heart rate.

Exercise testing is a valuable and relatively simple diagnostic procedure for detecting suspected angina pectoris and for evaluating the condition of patients with known coronary artery disease. However, the procedure is not 100% sensitive or specific.

One way of classifying patients subjected to stress electrocardiography is by the presence or absence of the symptom of chest pain.

1. In the presence of chest pain, a positive stress ECG may be of great diagnostic value. This finding may suggest with a great deal of certainty that the patient has coronary artery disease. A negative test, however, does not rule out coronary disease and, depending on the patient's risk-factor profile, other clinical findings, and recurrence of pain, further evaluation may be required.

2. In the absence of chest pain, on the other hand, a nega-

tive test is of more diagnostic value than a positive test. A positive test requires further evaluation to make the diagnosis with certainty.

Cardiac Catheterization

If evidence of ischemia, ECG changes, or suggestive chest pain is detected on stress electrocardiography, the next traditionally prescribed procedure is coronary arteriography.

Different terms are used interchangeably to describe this technique. They are:

Cardiac Catheterization: This term describes only the introduction of a catheter into the heart. The catheter may be introduced into one of the heart's chambers, or it may be guided into one of the coronary arteries. The precise diagnostic purpose of the catheterization is not indicated by this term.

Arteriography: By guiding the catheter up the femoral artery in the groin or the brachial artery, the angiographer can access the arteries of the heart as they branch off the aorta. Coronary arteriography involves the injection of a contrast agent, which is opaque to x-rays, into the coronary artery system, thus making it possible to visualize the coronary arterial anatomy. The term angiography, which actually describes the visualization of any blood vessel or vessel system by a similar technique, is often used interchangeably with arteriography.

Ventriculography: If the purpose of the catheterization procedure is to study the motion of the ventricles, radiopaque contrast agent is injected through a catheter into the ventricle. X-ray motion pictures will then reveal the movement of the ventricles through systole and diastole, and demonstrate wall motion abnormalities, including any dyskinesis indicative of aneurysm. Mitral valve regurgitation may also be detected.

Indications for Catheterization: There are several clinical settings in which hemodynamic and angiographic studies are commonly performed, although other specific indications or contraindications may exist in particular patients. These broad areas may be summarized as follows:

- ☐ In patients with acquired valvular heart disease, hemodynamic assessment and angiographic studies are often indicated to determine whether the nature and severity of the valvular defect render it amenable to surgical treatment.
- ☐ In patients with congenital heart disease, hemodynamic studies and angiography are often necessary to characterize the primary defect and to determine whether or not associated lesions are present.
- ☐ In patients with chest pain of undetermined cause, angiographic visualization of the coronary arteries may be indicated. In patients with known coronary artery disease, such studies can help determine whether or not surgical treatment is feasible and indicated. They are essential for precisely delineating the arterial lesions and the anatomy.
- ☐ In patients who have undergone cardiac surgery, cardiac catheterization studies to evaluate the success of the operation may be indicated, particularly when residual symptoms are present. Such studies may reveal malfunction of a prosthetic valve or residual disease of the ventricular myocardium.
- ☐ In patients with suspected myocardial disease, cardiac catheterization may be preformed to exclude lesions potentially amenable to surgical treatment, such as mitral regurgitation, coronary artery disease, constrictive pericarditis and idiopathic hypertrophic subaortic stenosis.
- ☐ In patients with evidence of pulmonary hypertension, cardiac catheterization may be performed to locate the "affecting" lesion, such as mitral stenosis, left-to-right shunts, multiple pulmonary emboli, or peripheral pulmonic stenosis.

Coronary Arteriography: Accurate visualization of the coronary vascular bed is a prerequisite for assessing coronary artery disease prior to coronary bypass procedures. The procedure allows the cardiologist and surgeon to judge the severity of stenosis (whether a given artery is 80% or only 50% stenosed, for instance) and to localize all lesions before surgery.

In the past, techniques for injecting contrast medium into the ascending aorta using retrograde arterial catheterization were used, with only partial success, to visualize the coronary vascular bed. Today selective, direct injection of contrast medium into each coronary artery offers much greater definition of these vessels. Contrast medium is injected into the right and left coronary arteries, with the patient placed in several oblique positions while cineangiograms are rapidly exposed. The films visualize obstructive lesions within branches of the coronary vessels; they also illuminate any coronary collateral circulation that may have developed.

Special Measurement Techniques: Intravascular pressure measurement within the chambers and blood vessels of the heart is ordinarily performed using a catheter-transducer system. The tip of the cardiac catheter is in communication with the transducer by means of the fluid column contained within the catheter lumen. Since such factors as movement of the catheter and presence of air bubbles can influence the dynamic accuracy of measurement of these catheter-transducer systems, miniature pressure gauges, which contain microtransducers attached directly to the catheter tip, are being used with increasing frequency.

Cardiac Output Measurements: Cardiac output is the amount of blood ejected by the heart per unit of time, reported as liters/min. Cardiac output is a measure of overall cardiac status and left ventricular performance in particular. Repeated cardiac output measurements are used to assess a cardiac patient's response to therapy.

The complexity of cardiac output determination has generally confined the procedure to the cardiac catheterization laboratory. The three most commonly used methods of determining cardiac output are the Fick method, the indicator-dilution method, and the thermodilution method. Although all are sound, each has its particular advantages and disadvantages.

Other techniques may use special catheters to record ECGs from the right atrium, the His bundle, and the ventricle in difficult-to-evaluate cases of arrhythmia and heart block. Other catheters, which measure phasic blood flow velocity in the coronary vessels or localize and characterize heart sounds and murmurs by intracardiac phonocardiography, are also available.

Stress Testing: Exercise performed in the supine position during cardiac catheterization can provide important information, different from that provided by the stress ECG, concerning the ability of the heart to respond to stress. For example, a patient with heart disease may have a normal cardiac output and normal intracardiac pressures at rest but markedly impaired cardiac output response or an abnormal elevation of ventricular diastolic pressure with exercise. Infusion of a pressor agent, instead of exercise, has also been used to test the cardiac response to stress.

Complications of Catheterization: The increasingly widespread application of cardiac catheterization procedures has increased the possibility that complications may ensue. At the same time, however, as experience has been gained, the morbidity and mortality associated with catheterization have been reduced.

Serious Arrhythmias: Ventricular tachycardia, ventricular fibrillation, and cardiac arrest are occasional complications of cardiac catheterization. Isolated premature ventricular contractions, atrial fibrillation, or supraventricular arrhythmias are usually of short duration, relatively easily controlled, and rarely of physiologic significance. Ventricular arrhythmias are most common during selective coronary angiography and left ventriculography. Catheter withdrawal and cardioversion usually restore sinus rhythm, after which the procedure may be continued.

Hypotension: Profound hypotension may be associated with ischemia, an allergic reaction to the contrast medium, systemic sepsis (infection), or a perforation of a chamber of the heart.

Emboli: Systemic and pulmonary emboli are occasional complications of cardiac catheterization. System emboli usually result from clots that form at the end of catheters and are flushed into the systemic circulation. Thrombophlebitis, usually at the site of venous catheterization, can result in pulmonary thromboembolism and pulmonary infarction.

Hemorrhage: Hemorrhage may occur at a site of entry into a vein or, more commonly, at an arterial entry. Heparin is commonly used during cardiac catheterization to prevent clotting, but it does increase the risk of serious bleeding.

Thrombosis: The arterial site of catheter entry may occasionally become thrombosed.

Echocardiography

In the past several years, echocardiography has been widely accepted as a clinically useful diagnostic technique. Like radionuclide imaging procedures, it is especially appealing to physicians because it is noninvasive and painless.

Ultrasound consists of sound waves emitted at a frequency of greater than 20,000 cycles/sec. Echocardiography makes use of pulse-reflected ultrasound to examine the functioning heart. Ultrasonic echoes from the heart have been shown to reflect abnormalities specific to a wide variety of heart diseases, including valvular, congenital, myocardial, and pericardial diseases. Because the anatomic components of the heart can be identified and their distances from the transducer can be measured, the sizes of the various chambers (right and left ventricle, left atrium) and vessels (pulmonary artery and aorta) can be accurately estimated.

Figure 2 shows how the ultrasound beam traverses the heart and scans a sector of the left ventricle in order to record a left ventricular echogram. A transducer that both emits pulsed ultrasound waves and receives echos is placed on the patient's chest, initially at the third to fifth intercostal space and into the left sternal border. As a continuous recording is made on the strip chart, the transducer is tilted laterally and inferiorly so that the echo beam scans the left ventricle from the mitral valve area to the apex, or superiorly and medially to scan from the mitral valve to the aortic valve. Sector scans are made from multiple intercostal spaces and locations in order to examine various left ventricular segments.

In the critically ill or clinically unstable patient, echocardiography provides a safe, painless, and yet reliable bedside method for evaluating the anatomy and physiology of the heart. In addition, the procedure can be repeated serially as often as clinically indicated to monitor and detect hemodynamic changes that may be of prognostic value to the clinician. The ultimate role of echocardiography in coronary artery disease is not yet known. For the individual patient with coronary artery disease, it is too early to know whether the information available from the echocardiogram will be useful in influencing the course or outcome of the disease.

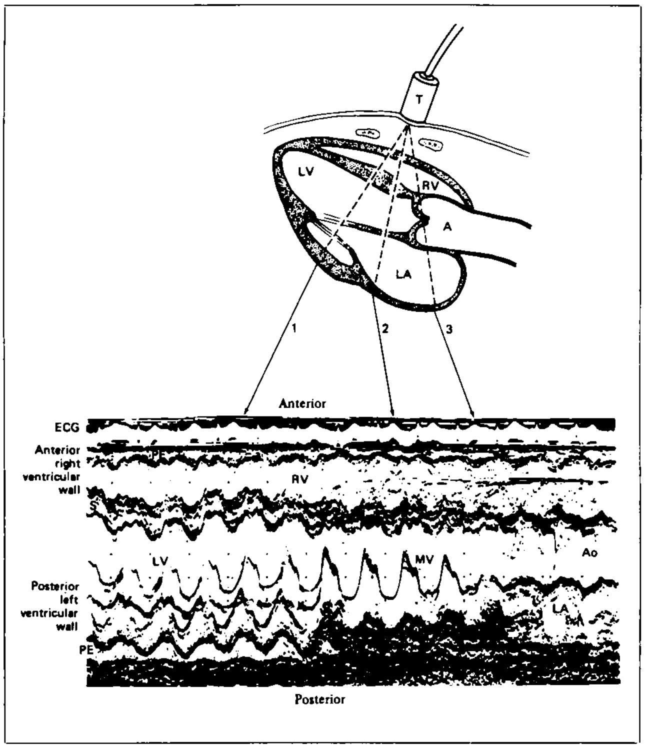

FIG. 2. Echocardiogram demonstrates normal intracardiac structures in a patient with pericardial effusion. During recording, the transducer was moved from position 1 to position 3. RV = right ventricular cavity; LV = left ventricular cavity; S = septum; MV = mitral valve; AO = aorta; and LA = left atrium.

Acknowledgments

Marvin Konstam, MD, Assistant Professor in Medicine and Radiology, Director of Nuclear Cardiology, New England Medical Center, Boston, MA, and Ann Steves, CNMT, MS, Educational Coordinator, Nuclear Medicine Technology, VA Medical Center, Buffalo, NY, are acknowledged for their assistance in the preparation of this series.

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