Cardiac Stress Testing for Diagnosis of Coronary Artery Disease in Adults with Acute Chest Pain

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Chest pain is a leading cause of visits to the emergency department (ED), accounting for 5% of the 115 million ED visits in the United States in 2005.[1] A key concern in evaluating chest pain is ruling out CAD as the cause. Alternative etiologies are numerous, including aortic stenosis, hypertrophic cardiomyopathy, hypertensive urgency, and esophageal, lung, and chest wall conditions.[2] In addition, coronary artery angiography can reveal Kawasaki disease, coronary artery spasm, coronary artery anomaly, or dissection.[2] The approach to excluding CAD in a patient with chest pain begins with a pertinent history, physical examination, and electrocardiogram (ECG). Findings on these initial assessments dictate further evaluation, which can include serum cardiac enzyme assay, chest radiographs, and cardiac stress tests (**Table 1**). Physicians should be familiar with the various stress testing modalities and be able to select an appropriate test based on a patient's risk profile and other factors. This article discusses the use of stress tests for diagnosis and risk stratification of patients with suspected CAD, with a focus on test methods and test selection.

TAKE HOME POINTS

- Deciding whether to perform a cardiac stress test to assess for coronary artery disease (CAD) in an adult with chest pain as well as the selection of a specific test begins with determining the patient's pretest probability of CAD.
- For patients with low pretest probability of CAD, attention is focused on identifying noncardiac causes of chest pain. Exercise stress testing (EST) without imaging is a reasonable screening test if desired.
- EST is recommended by American College of Cardiology/American Heart Association guidelines as the initial test in patients with intermediate pretest probability of CAD.
- Imaging as an adjunct to EST incrementally improves the insight of CAD testing when chosen for the proper patient populations, which include those with an abnormal EST, intermediate and high pretest probability of CAD, or depressed ST segment on baseline electrocardiogram.
- Choosing among stress echocardiography and nuclear imaging depends on a patient's risk for CAD, electrocardiographic findings, and comorbidities as well as local expertise in the modalities.

STRESS TEST MODALITIES AND METHODS

Tests to evaluate for the presence of CAD assess either cardiac function or anatomy. Stress tests are functional tests that demonstrate the consequence of inducible myocardial ischemia on ECG or imaging (**Figure 1** and **Figure 2**).[3,4] Stress on the heart in a patient with CAD initiates a cascade of events in which inadequate myocardial oxygen delivery precedes left ventricular diastolic and systolic dysfunction by 10 to 20 seconds, which manifests on ECG as nonspecific ST-T wave abnormalities and clinically as angina pectoris.[5] Hemodynamically significant lesions in the coronary arteries must be present for functional tests to be abnormal.[3]

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Table 1. Approaches to Detecting Coronary Artery Disease (CAD)

Pretest history
Symptomatic classification of chest pain
Framingham 10-year CAD risk for outpatients
Presence of CAD risk equivalents (diabetes, stroke, peripheral vascular disease, aortic aneurysm)
Functional tests to detect the consequences of ischemia
Exercise stress testing: shows electrocardiogram changes
Stress echocardiogram: shows wall motion changes
Nuclear imaging (SPECT MPI): shows perfusion changes
Cardiac magnetic resonance imaging (myocardial tagging): shows myocardial metabolism and viability
Atherosclerotic imaging
Coronary artery calcium scoring by computed tomography
Computed tomography angiography
Magnetic resonance angiography
Coronary artery angiography with left ventriculography
Extracardiac and novel markers
Carotid intima media thickness
Ankle-brachial index
Brachial artery reactivity testing
Endothelial dysfunction testing with acetylcholine
Ambulatory ST-segment monitoring
C-reactive protein level
B-type natriuretic peptide level

SPECT MPI = single photon emission computed tomography myocardial perfusion imaging.

The basic cardiac stress test is the exercise stress test with ECG monitoring, or EST. This test monitors symptoms and ECG changes associated with ischemia. In addition to EST evaluation for CAD, imaging of the heart can be performed. Cardiac imaging reveals reversible defects in cardiac function or blood supply. Stress echocardiogram measures wall motion and dilation before and after stressing, and changes in wall motion function are considered positive for possible CAD. Nuclear studies, such as single photon emission computed tomography (SPECT) myocardial perfusion imaging, measure blood flow to the heart before and after stress. Changes in blood flow are considered positive for possible CAD. There are reversible and fixed blood flow defects, the latter of which is considered consistent with an infarct. If a patient has an abnormal result on a stress test, coronary artery catheterization may be performed. Patients at high risk for mortality from CAD may proceed directly to coronary angiography in order to avoid the possibility of a false-negative stress test.[6]

In cases where exercise is not possible, pharmacologic agents can be used to stress the heart.[7–9] However, a normal exercise stress test is more reassuring than a normal pharmacologic stress test.[8] Pharmacologic agents used for stress testing include adenosine, dipyridamole, and dobutamine. Adenosine and dipyridamole are perfusion agents most frequently used with nuclear imaging of the heart, although they can be used with all types of stress tests. The agents are administered over a course of minutes.[10] Usually myocardial ischemia is not induced, but patients with severe lesions may have ischemia.[11] Aminophylline can reverse the side effects of ischemia induced by dipyridamole. Undesirable effects of pharmacologic agents include atrioventricular nodal block, peripheral vasodilation, and bronchospasm.[11] Hypotension, uncontrolled asthma, severe chronic obstructive pulmonary disease, second- or third-degree heart block, and use of oral dipyridamole are contraindications to their use.[10,11]

Dipyridamole increases arterial levels of adenosine, which in turn induces vasodilation of coronary arteries, resulting in a fourfold increase in myocardial blood flow.[9,11] Arteries with arteriosclerosis do not respond to the vasodilating effects of dipyridamole, and a relative perfusion difference can be imaged.[9] Blood flows to the path of least resistance, thus bypassing an area of stenosis and creating a perfusion defect on imaging.

Dobutamine stimulates cardiac β receptors, causing increased heart rate, blood pressure, and contractility in a dose-related fashion.[11] These effects cause increased blood flow to myocardium supplied by normal arteries, while flow is increased to a lesser extent in areas supplied by stenotic vessels.[9–11] This flow differential is significantly less than that obtained with adenosine or dipyridamole because the tachycardia induced by dobutamine abbreviates diastolic filling time.[11] Patients with recent myocardial infarction, unstable angina, uncontrolled hypertension, tachyarrhythmias, severe aortic stenosis, or aneurysm should not receive dobutamine.[11] Also, recent β-blocker use can attenuate response.

Exercise Stress Testing

EST is a cardiovascular test in which exercise on a treadmill or cycle ergometer is used to increase cardiac effort while the patient undergoes electrocardiographic and blood pressure monitoring.[10] The advantages of EST include low cost, ease of testing in ambulatory settings, ability to be performed by credentialed noncardiologists, and low risk for complications. Risk of infarction or death during EST is estimated at 1 event per 2500

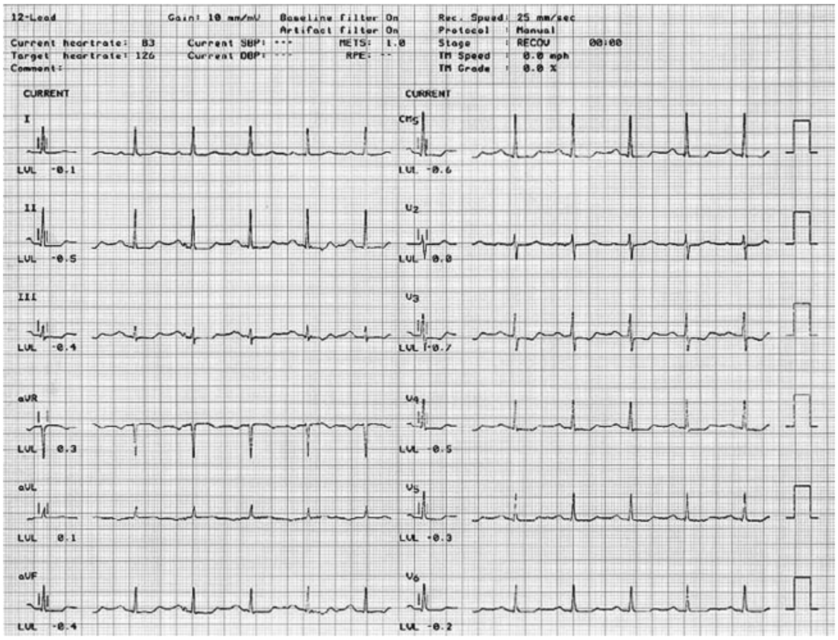

Figure 1. ST-segment depression in anterior and inferior leads that is most pronounced in lead V_3 in a patient who underwent cardiac stress testing with adenosine infusion. (Reprinted with permission from Szulc M, Wong FJ. Adenosine myocardial perfusion imaging in a female patient with chest pain. Available at www.willab.com/adenocase/new_cases/wong-szulc02/index2.html. Accessed 25 Sep 2008.)

tests.[12,13] The test is considered abnormal if (1) ischemic chest pain occurs, and/or (2) horizontal or down sloping ST depression of 1 mm or greater occurs, or (3) ST elevation of 1 mm or greater occurs. A blunted blood pressure response or hypotension may suggest multivessel or a high-grade coronary artery lesion, such as in the left main artery.[14,15] EST should not be used in patients with abnormalities of the ST segment in lead V_5, which make interpretation unreliable. Full EST standards are available from the American Heart Association (AHA).[15]

Patients referred for EST must be able to walk briskly on a treadmill to achieve a goal heart rate of 85% to 100% of the age-predicted maximum calculated from the formula: 220 – age.[10] Obstacles to the use of exercise include musculoskeletal problems, lung disease, vascular disease, or lack of motivation.[11] In these instances, a pharmacologic stress is an alternative. A report of the EST is made that includes the patient's symptoms, exercise capacity, blood pressure pattern, ECG changes, and overall risk assessment for CAD.[2]

Studies comparing EST with the gold standard of coronary angiography in groups that excluded post–myocardial infarction patients and other biases found a sensitivity of 50% and specificity of 90% for detecting coronary lesions that obstruct over 50% of the lumen diameter.[16] Meta-analysis of more inclusive studies revealed a sensitivity of 67% and specificity of 72% for CAD (**Table 2**).[4,9,16–20] A number of prediction equations for use in conjunction with EST have been proven valid for patients without established CAD over a 5-year follow-up. The Duke treadmill score categorizes patients as low, intermediate or high risk using exercise time, exercise capacity (as metabolic equivalents), and whether exercise angina occurred to predict posttest probability of CAD.[10,21] Others have developed and validated a treadmill score that incorporates maximum heart rate, exercise ST depression, age, angina history, smoking, diabetes, estrogen status, and whether angina stopped the test.[22,23]

Stress Echocardiogram

Two-dimensional echocardiography can provide information about the anatomy of the myocardium, cardiac valves, and great vessels as well as information about the function of the right and left ventricles of the heart at a relatively low cost.[18] Echocardiography can show left ventricular systolic or diastolic dysfunction, the extent of wall-motion abnormalities from myocardial infarction, and the presence of stress-induced ischemia. Stress echocardiography can be accomplished with the same exercise or chemical agents used for EST and nuclear cardiac studies. In performing this test, a baseline resting image of heart function is first obtained by a technician using a handheld ultrasound transducer, and then blood pressure and ECG monitoring is started while the patient's heart is stressed. The test is stopped if there are concerning ECG changes, if limiting chest pain occurs, or once the goal heart rate is obtained. Repeat imaging of the stressed heart is then obtained. The patient's body habitus can be a limiting factor in obtaining useful images.

Stress echocardiography with pharmacologic agents may have a lower sensitivity for detecting single-vessel

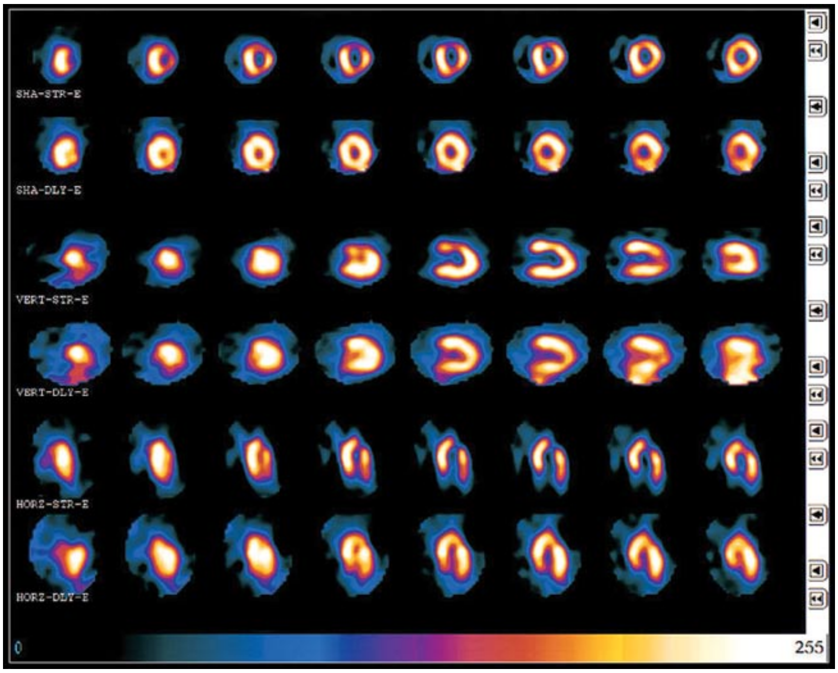

Figure 2. Stress-induced ischemia in the anterior, inferior, and lateral walls detected on nuclear myocardial perfusion imaging. The ischemia is most pronounced in the bottom 2 rows demonstrating differences in perfusion with stress (STR) and rest (DLY). (Reprinted with permission from Szulc M, Wong FJ. Adenosine myocardial perfusion imaging in a female patient with chest pain. Available at www.willab.com/adenocase/new_cases/wong-szulc02/index2.html. Accessed 25 Sep 2008.)

Table 2. Sensitivities and Specificities of Tests for Coronary Artery Disease

Test	Sensitivity, %	Specificity, %
Exercise stress test	67	72
Exercise stress echo	81	86
Dobutamine stress echo	75–93	79–92
Adenosine stress echo	62–79	88–93
Dipyridamole stress echo	66–74	90–95
Dobutamine SPECT	77–87	70–79
Adenosine SPECT	89–92	70–79
Dipyridamole SPECT	84–93	54–74
Coronary artery calcium score	87–91	91–96
MRI angiography	72	86

Data from references 4, 9, 16–20.

Echo = echocardiogram; MRI = magnetic resonance imaging; SPECT = single photon emission computed tomography.

disease than for multivessel disease.[9] Reported sensitivities range from 75% to 93% and specificities range from 79% to 92% (Table 2).[9,18,19]

Nuclear Stress Testing

SPECT myocardial perfusion imaging (SPECT MPI) is a nuclear medicine study that uses a gamma camera to obtain images of the heart in 2 dimensions from multiple angles. These data are then reconstructed by computer software into 3 dimensional data which can be viewed in slices on different axes. The camera is rotated around the patient similar to a conventional computed tomography (CT) scan; however, image acquisition time with SPECT is longer (15–20 min) than that of CT scan. Multiheaded cameras can shorten imaging time. SPECT imaging can be triggered by ECG monitoring to obtain images at a specific point in the cardiac cycle, a technique called gating.[24] Gated SPECT allows consideration of wall motion and thickening in the interpretation of the images, which can increase specificity by helping to differentiate true perfusion abnormalities from artifacts such as breast and diaphragm attenuation.[25] Left ventricular ejection fractions are also computed with the use of cardiac gating.[25]

The radiotracers routinely used in MPI are thallium and the technetium (Tc 99m) tracers sestamibi, tetrofosmin, and teboroxime.[10,11,26] Thallium 201 (Tl-201) is an analogue of potassium that is renally excreted. The Tc 99m tracers are lipid soluble, extracted by the hepatobiliary system, and excreted through the gastrointestinal tract. The imaging procedure is performed with 1-day and 2-day protocols. In the ideal scenario, stress and rest images are obtained on separate days to avoid residual activity from the initial radiotracer interfering with subsequent images.[11] This protocol is preferable in large or overweight individuals (> 250 lb or body mass index > 30 kg/m^2) or in women in whom breast attenuation is anticipated.[11] Although the lower initial dose used in the 1-day protocol may result in suboptimal images, the

1-day protocol is almost universally used because it is logistically preferable. The initial test dose of tracer is usually one quarter of the total dose to be given. The remaining three quarters are administered during the second portion, usually without delay between tests. Whether to perform rest or stress first has not been fully established.[11] Use of 2 different isotopes (Tl-201 for rest images and Tc 99m for stress images) results in a shorter duration of the entire procedure but increases the patient's radiation exposure.[11]

Stress of the heart for imaging can be accomplished through exercise or induced chemically with adenosine, dipyridamole, or dobutamine. When pharmacologic agents are used to induce cardiac stress, the radionuclides are administered in close conjunction. For patients able to achieve 85% of their maximum predicted heart rates, exercise is the preferred method of stress.[11]

A review of studies by the American College of Cardiology (ACC), AHA, and American Society of Nuclear Cardiology (ASNC) showed that SPECT MPI with exercise protocol has an average sensitivity of 87% and specificity of 73%.[27] SPECT MPI using a vasodilator (dipyridamole or adenosine) has a sensitivity of 89% and a specificity of 75% for atherosclerotic narrowing of 50% or greater.[27]

NOVEL SCREENING METHODS

Novel methods of screening for CAD that complement stress tests include coronary artery calcium scoring, CT coronary angiography, cardiac magnetic resonance imaging, magnetic resonance angiography, carotid intima media thickness, endothelial vasomotor dysfunction testing, brachial artery reactivity, ankle-brachial index, ambulatory ST-segment monitoring, B-type natriuretic peptide level, and C-reactive protein level. A cost-utility benefit of these methods has not been established, nor have they been shown to improve outcomes.[4,17,28,29] Of these tests, calcium scoring and CT angiography have generated considerable interest in recent years.

Calcification occurs in atherosclerotic coronary arteries. A calcium score can be calculated based on measurements obtained using a fast, thin-slice CT scanner. The rate of myocardial infarction or CAD death has been correlated with the burden of calcification,[30] although the utility of calcium scoring has yet to be validated. There are reports of its "incremental prognostic value" when used to complement traditional risk stratification methods. For example, an asymptomatic person at intermediate risk may be restratified as at high risk based on calcium score.[30] The ACC/AHA guidelines conclude that for symptomatic patients calcium scoring should be relegated to second-line testing.[30]

CT angiography uses a fast, thin-slice CT scanner to measure coronary artery atherosclerosis. It is sensitive and specific in detecting calcified and noncalcified stenoses that exceed 50% of artery diameter.[3,31] CT angiography has the potential to provide a single test to assess for pulmonary embolus, aortic dissection, and acute coronary syndrome as the cause of chest pain in the acute setting.[3] Some authors are proponents for its further evolution to complement or even replace the more familiar imaging studies such as nuclear SPECT.[3] Patients with elevated creatinine or contraindications to exposure to contrast dye have been excluded from studies of CT angiography.[31,32]

SELECTING A STRESS TEST

Risk Stratification for CAD

Estimating the pretest probability of CAD as low, intermediate, or high is a necessary first step in selecting a diagnostic test for CAD. The various definitions of risk focus on timeframes ranging from 1 day to 10 years as well as focus differently on the probabilities of CAD, myocardial infarction, or mortality from CAD (**Table 3**).[2,6,24,28,33] Nonetheless, the basic determinants of pretest probability for CAD in a patient with chest pain are age, gender, and the type of chest pain (ie, typical angina, atypical chest pain, and nonanginal pain).[34] In this method devised by Diamond and Forrester,[34] *typical angina* is defined as chest pain that is (1) substernal, (2) brought on by exertion or emotional distress, and (3) relieved by rest or nitroglycerin; *atypical chest pain* lacks 1 of these 3 features, and *nonanginal pain* has 1 or none of the features of typical chest pain. Men and older patients have higher rates of CAD. The pretest probability of CAD estimated based on these factors (**Table 4**) is then used to make recommendations for CAD testing and is the starting point for risk stratification.[35] Using the Diamond and Forrester classification of angina as a building block for more complex risk stratification, an abnormal exercise stress electrocardiogram (EST) in high-risk patients can have a positive predictive value for CAD as high as 92%.[6] For those at intermediate and low risk, an abnormal EST can have a positive predictive value of 62% and 21% for CAD, respectively.[6]

The well-known Framingham risk score classifies patients as at low, intermediate, or high risk for myocardial infarction or death from CAD over 10 years. Using the 6 patient characteristics of age, gender, total cholesterol, high-density lipoprotein cholesterol level, smoking status, and systolic blood pressure, a patient's predicted 10-year risk can be categorized as less than 10% (low risk), 10% to 20% (intermediate risk), or over 20% (high risk).[36] This risk assessment tool can be

Table 3. Risk Stratification Systems with Testing Recommendations for Detecting Coronary Artery Disease (CAD) in Patients with Chest Pain

		Risk Level with Basis of Classification and Testing Recommendation		
Author (yr)	**Stratification Method**	**Low**	**Intermediate**	**High**
Garber and Solomon (1999)[24]	Diamond and Forrester	Pretest probability of CAD < 25% Recommendation not specified	Pretest probability of CAD 25%–75% Stress with imaging or coronary artery angiography	Pretest probability of CAD > 75% Recommendation not specified
Morise (2000)[6]	Modified Diamond and Forrester	PPV of positive EST 21% for current CAD No testing or EST without imaging	PPV of positive EST 62% EST without imaging	PPV of positive EST 92% Coronary artery angiography
Williams et al (2001)[2]	Risk of CAD mortality by Duke treadmill score	Risk < 1% Stress without imaging	Risk 1%–3% Stress with imaging	Risk > 3% Coronary artery angiography
Smith (2006)[28]	Framingham study 10-yr risk for CAD/annual risk for CAD	10-yr risk < 10%, annual risk < 0.6% Periodic reassessment of risk	10-yr risk 6%–20%, annual risk 0.6%–2% Recommendation not specified	10-yr risk > 20%, annual risk > 2% Recommendation not specified
Mieres et al (2007)[33]	Framingham study 10-yr risk for CAD/annual risk for MI	10-yr risk < 10%, annual risk < 0.6% EST without imaging	10-yr risk 10%–20%, annual risk 0.6%–2% EST with imaging or coronary artery calcium scoring	10-yr risk > 20%, annual risk > 2% EST with imaging

EST = exercise stress testing; MI = myocardial infarction; PPV = positive predictive value.

Table 4. Pretest Probability of Coronary Artery Disease (CAD) Based on Age, Sex, and Symptoms

Age, yr	Sex	Nonanginal Chest Pain	Atypical Angina	Typical Angina
30–39	Male	Low	Intermediate	Intermediate
	Female	Very low	Very low	Intermediate
40–49	Male	Intermediate	Intermediate	High
	Female	Very low	Low	Intermediate
50–59	Male	Intermediate	Intermediate	High
	Female	Low	Intermediate	Intermediate
60–69	Male	Intermediate	Intermediate	High
	Female	Intermediate	Intermediate	High

NOTE: Probability levels are defined as follows: high, > 90% pretest probability of CAD; intermediate = 10%–90% pretest probability of CAD; low = < 10% pretest probability of CAD; very low = < 5% pretest probability of CAD.

Adapted with permission from Gibbons RJ, Balady GJ, Bricker JT, et al. ACC/AHA 2002 guideline update for exercise testing. Available at www.acc.org/qualityandscience/clinical/guidelines/exercise/exercise_clean.pdf. Accessed 18 Sep 2008.

accessed online at http://hp2010.nhlbihin.net/atpiii/calculator.asp?usertype=prof.

Additional risk factors that predict the possibility of CAD are the presence of diabetes mellitus, peripheral vascular disease, and cerebral vascular disease.[17] Because atherosclerosis is a systemic process, the presence of arterial disease elsewhere often implies its presence within the coronary arteries.

Other Assessments

In addition to pretest probability for CAD, factors that must be considered when deciding whether to order a stress test include the patient's interest in invasive interventions, comorbid conditions, ability to exercise, and ability to comply with long-term antithrombotic medication. It is necessary to assess preferences about revascularization since the results of stress testing may lead to a recommendation for invasive testing and revascularization. However, invasive tests for CAD offer little benefit to patients who choose to avoid revascularization or who are poor candidates. These patients are best served by medical management alone if testing will not change the treatment plan. Once pretest probability and the patient's interest in interventions have been determined, the selection of a screening test for CAD depends on a patient's ECG findings and exercise capacity. Several patterns seen on ECG may dictate which test to pursue (**Table 5**).[2] For patients with a duration of nonworrisome symptoms greater than 2 weeks and no ECG changes, outpatient stress testing can be done.[2]

Low-Risk Patients

For adults with a low pretest probability for CAD, management focuses on diagnosing and treating noncardiac

Table 5. Indications and Contraindications for Coronary Artery Disease (CAD) Testing by Method

Type of Stress Test	Mechanism of Action	Indications	Contraindications
All types	—	Symptomatic patients with intermediate risk for CAD Perhaps patients with high risk for CAD History of known CAD	Patient disinterest in invasive interventions; acute myocardial infarction; unstable angina; hypotension; severe hypertension; pulmonary embolus; myocarditis; pericarditis; left main vessel disease; electrolyte imbalance
EST	Detects symptoms and ECG changes of ischemia	Symptomatic patients with intermediate risk for CAD Perhaps patients with low risk for CAD	High pretest probability of CAD; ST-segment abnormality at V_5; ST depression > 1 mm at baseline ECG; T-wave inversion consistent with strain pattern; left bundle branch block; preexcitation syndrome; uncontrolled heart failure
Stress echocardiography	Detects functional changes in heart wall motion	Symptomatic patients with abnormal EST Symptomatic patients with intermediate risk for CAD Left bundle branch block	Limiting habitus such as obesity or emphysematous changes; low risk for CAD; severe aortic stenosis or outflow obstruction such as hypertrophic cardiomyopathy
SPECT MPI	Detects perfusion changes after stress	Symptomatic patients with intermediate risk for CAD Uninterpretable ECG Left bundle branch block Paced rhythm Preexcitation syndrome Perhaps high risk for CAD	Low risk for CAD; ST-segment elevation
Exercise	Increases cardiac activity, oxygen delivery demand, and ischemia	Ability to exercise	Unable to obtain heart rate 85% of maximum; left bundle branch block; use of digoxin; preexcitation syndrome
Vasodilator (dipyridamole or adenosine)	Induces "steal" from atherosclerotic areas	Unable to exercise	Severe COPD; second- or third-degree heart block; oral dipyridamole use; caffeine use
Dobutamine	Inotrope and chronotrope that increases oxygen demand, inducing ischemia	Unable to exercise	β-Blocker use (relative contraindication); preexcitation syndrome
Coronary artery angiography	Fluoroscopic imaging of the coronary arteries with left ventriculography	Abnormal stress test; symptomatic heart failure; serious ventricular arrhythmia; perhaps high risk for CAD	—

COPD = chronic obstructive pulmonary disease; ECG = electrocardiogram; EST = exercise stress testing; SPECT MPI = single photon emission computed tomography myocardial perfusion imaging.

causes of chest pain.[2] Testing is not usually recommended as these patients have a greater likelihood of false-positive tests, which may lead to invasive testing and additional risk.[6] Normal EST results are reassuring, but positive EST results are likely falsely positive in patients with low pretest probabilities.[6] If diagnostic testing is desired in low-risk individuals, EST is a reasonable choice since it is low cost and noninvasive (Table 5).[6,13] ACC/AHA guidelines state that there is no compelling evidence that imaging provides additional useful information for patients at low risk by history and treadmill score.[13] These patients can be managed medically with risk factor modification and search for noncardiac causes of chest pain.[2] Patients with low pretest probability but an intermediate risk treadmill score may benefit from stress testing with imaging for further risk stratification.[2] If imaging results are normal, these patients can be managed medically.

Intermediate- and High-Risk Patients

EST is most useful for diagnosing obstructive CAD in adults with an intermediate pretest probability, and is recommended by ACC/AHA guidelines as the initial test in patients with intermediate pretest probability of CAD.[13] Adults with intermediate pretest probability will have a greater change between pre- and posttest probability as compared with patients having low or high pretest probability, and this change is useful to guide future care. Adults with high pretest probabilities (eg, men aged ≥ 40 yr with typical angina) or known CAD will still have high posttest probability with a negative EST, making the test less useful in this population.[6]

Imaging as an adjunct to EST incrementally improves the insight of CAD testing when chosen for the proper patient populations.[33,37] Indications for imaging include abnormal EST, intermediate and high pretest probability for CAD, history of intervention for CAD, left bundle branch block, depressed ST segment on baseline ECG, a paced rhythm, or a preexcitation syndrome (Table 5).[2,4,33] In symptomatic patients with normal cardiac enzyme testing and no ST-segment elevation, SPECT MPI and stress echocardiography have been shown to be an insightful method of detecting CAD.[16,38–42] If imaging results are normal, these patients can be managed medically.

When choosing between nuclear imaging and echocardiography, the abilities of local expert providers in performing and interpreting these tests should help guide selection of a technique. An exercise or dobutamine stress echocardiogram is often cited as a "good compromise" of sensitivity and specificity for CAD, and is cost-effective by usual medical economic analysis.[9,24] Contraindications to stress echocardiography include inability to hold β-blocker use, left bundle branch block, and left ventricular outflow obstruction such as hypertrophic cardiomyopathy or aortic stenosis.[43] Nuclear stress testing may be safer or more accurate in these instances. According to appropriateness criteria for SPECT MPI developed by the ACC in conjunction with the ASNC,[42] SPECT MPI is appropriate for symptomatic patients with chest pain syndrome who have intermediate or high pretest probability of CAD with interpretable ECG and the ability to exercise, for patients with intermediate or high pretest probability with uninterpretable ECG, and for patients unable to exercise. For patients with acute chest pain, SPECT MPI is appropriate for those at intermediate risk with normal cardiac enzyme testing and no ST-segment elevation. It is inappropriate to use SPECT MPI for patients with low probability of CAD. It can be considered in those with unstable angina or non–ST-segment elevation myocardial infarction but is not appropriate in patients with ST elevation.

Consideration of coronary artery angiography versus stress testing with imaging can be made for patients with high pretest probability of CAD given the possibility of a false-negative result with stress testing.[2,6,33] Other indications for coronary angiography include symptomatic known systolic heart failure and serious ventricular arrhythmia.[2]

COST AND WARRANTY OF RESULTS

The cost of stress testing is an important consideration. In 1996 US dollars, echocardiogram cost an additional $5000 per quality-adjusted life-year saved (QALY) compared with EST alone for patients with intermediate probability of CAD.[24] Use of nuclear studies cost an additional $78,000 per QALY compared with stress echocardiogram.[24] The abilities of local expert providers in nuclear imaging and echocardiography should help guide selection of a technique for noninvasive cardiac evaluation.

The "warranty" of a normal stress result may be 1 to 2 years for those who can perform an exercise test with imaging. Studies have shown that patients with normal exercise stress tests have a 0% to 1.8% occurrence of myocardial infarction per year after normal results.[8,37] Those who cannot exercise, those with diabetes, and those who are older may have higher risks for events after a normal stress test.[8,37]

SUMMARY

The best screening test for CAD depends on a patient's probability for CAD, ECG findings, and exercise capacity.[2] Patients with low probability of CAD can be managed by diagnosing and treating noncardiac causes of chest pain. If diagnostic testing is desired in low-risk individuals, EST is a reasonable choice since it is cost-effective and noninvasive. ACC/AHA guidelines recommend EST as the initial test in patients with intermediate pretest probability of CAD.[13] The addition of cardiac imaging lends incremental insight for detection of CAD, most markedly for patients at intermediate probability for CAD. Exercise or dobutamine stress echocardiography may be a good compromise of sensitivity and specificity for CAD, and is cost-effective by usual medical economic analysis.[9,24] A normal exercise stress test is more reassuring than a normal pharmacologic stress test. For those with high probability of CAD, consideration of coronary artery angiography versus stress imaging can be made. **HP**

Test your knowledge and comprehension of this article with the *Clinical Review Quiz* on page 30.

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