American College of Radiology
ACR Appropriateness Criteria®

Clinical Condition: **Chronic Chest Pain — High Probability of Coronary Artery Disease**

Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	9	Helpful to exclude a noncardiac cause for chest pain.	Min
SPECT MPI	9	Effective for evaluating myocardial perfusion.	High
US echocardiography transthoracic stress	7	If coronary arteries are normal, and concern involves structural heart disease.	None
US echocardiography transthoracic	7	Can be used to demonstrate LV regional dysfunction due to ischemia and excellent for regional wall motion abnormalities.	None
CTA coronary arteries	7	Can be used to noninvasively visualize the coronary arteries. Excellent to assess coronary disease with multidetector scanners. May be useful in low-risk population but has not been studied in this population.	High
Arteriography coronary	7	The definitive test for establishing the diagnosis and directing treatment if clinical suspicion of CAD is high, or if there is an abnormal noninvasive imaging test.	Med
MRI heart function and morphology with or without contrast	6	Can be used to noninvasively evaluate LV regional dysfunction and areas of prior MI.	None
PET heart stress	6	Especially for patients who may not be optimal for conventional nuclear imaging (ie, obese patients).	High
CT coronary calcium	5	Negative test highly accurate in excluding CAD. Indicated in appropriate population where a pretest probability of zero calcium score is high.	Med
MRI heart with stress with or without contrast	5	Stress studies should only be performed at sites with appropriate expertise and equipment, due to safety concerns.	None
CT chest with contrast	4	Could be used to establish a noncardiac cause for chest pain. Possible utility in aortic dissection and potential pulmonary abnormalities.	Med
US gall bladder	3	Only if complete cardiac workup is negative. Can be used to exclude a noncardiac cause for chest pain.	None
MRA coronary arteries	2	May be indicated in patients unable to receive iodinated contrast, at sites with extensive expertise.	None
Rating Scale: 1=Least appropriate, 9=Most appropriate			*Relative Radiation Level

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Summary of Literature Review

Chronic chest pain of suspected cardiac origin is usually a consequence of myocardial ischemia. This is usually caused by fixed stenosis (atherosclerotic plaques), coronary spasm, microvascular disease, or a combination of the three. Chest pain of cardiac ischemic origin represents an imbalance between myocardial oxygen demand and coronary blood flow, and chronic pain can occur in patients with normal coronary arterial caliber for whom the primary cardiac pathology is extracoronary, (eg, aortic stenosis, hypertrophic cardiomyopathy). Nonischemic cardiac pain may be caused by pericarditis. While the syndrome of exertional angina pectoris is nearly always diagnostic for chronic coronary arterial disease, other extracardiac etiologies should be considered, especially for nonexertional or atypical chest pain, such as esophageal reflux and spasm, biliary disease, costosternal syndrome, and cervical radiculitis.

In patients with chronic chest pain, imaging has a major role in determining and documenting the presence, extent, and severity of myocardial ischemia and/or the presence, site, and severity of obstructive coronary lesions. Imaging findings are an important factor in determining the course of management of patients with suspected chronic myocardial ischemia in order to determine those patients best suited for medical therapy, angioplasty/stenting, or surgery. Imaging is also necessary to evaluate left ventricular function because ejection fraction and end systolic volume are important in predicting the long-term prognosis and likely benefit from various therapeutic options. Imaging studies are also required to demonstrate abnormalities such as aortic stenosis and hypertrophic cardiomyopathy, which can produce angina in the absence of coronary obstructive disease.

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The historically established imaging studies that may be used in evaluating suspected chronic myocardial ischemia are chest radiography, radionuclide myocardial perfusion imaging and ventriculography with and without stress; and catheter-based coronary angiography, and left ventriculography. Stress echocardiography (echo) and computed tomography (CT), both electron beam and multidetector CT (MDCT), have made significant progress in the evaluation of ischemic heart disease. Positron emission tomography (PET) is also now available for this purpose. Cardiac magnetic resonance imaging (MRI), while making significant headway in the diagnosis of infarction, is less widely used for stress-induced ischemia. In those patients who do not present with signs classic for angina pectoris, or in those patients who do not respond as expected to standard management, the exclusion of noncardiac causes of chronic chest pain require the use of additional studies, including esophagography, upper gastrointestinal series, and biliary imaging with ultrasound (US).

Chest Radiography

The chest radiograph is an inexpensive test that can rapidly demonstrate many noncardiac causes of chronic chest pain, including a variety of diseases of the mediastinum, pleura, or lung. It may also provide qualitative information about left ventricular function as reflected in cardiac size and pulmonary venous status. However, radiography can neither establish nor exclude chronic ischemic heart disease. It is relatively insensitive for detecting coronary arterial calcification. Also, fluoroscopy cannot reliably detect coronary artery disease (CAD) [1].

Radionuclide Imaging

Stress myocardial perfusion imaging demonstrates relative myocardial perfusion defects, indicating the presence of myocardial ischemia. For this reason, it is considered an important first line study in the evaluation of patients with chronic chest pain. The territory of the perfusion defect identifies the likely culprit coronary artery and can sometimes distinguish between significant single-vessel and multi-vessel coronary arterial obstruction(s) [2-11]. The rest and redistribution perfusion scans demonstrate reversibility (ischemia) or irreversibility (infarction) of the perfusion defect.

Technetium 99^{m} sestamibi has been shown to be more specific for ischemia when compared to thallium [10]. In a meta-analysis of 20 published studies including 488 patients studied with technetium 99m sestamibi, sensitivity and specificity were calculated to be 81% and 66% respectively with positive and negative predictive values of 71% and 77% respectively for detecting hibernating myocardium [3]. Limitations of stress myocardial perfusion imaging are its relatively high cost, difficulties with interpretation (especially in women), and difficulties imaging obese patients.

Stress radionuclide ventriculography (RNV) consists of measurement of the ejection fraction and assessment of regional wall motion at rest and at the peak of stress. This technique can be used to identify patients with "balanced" 3-vessel disease, which can be missed in perfusion studies and for differentiating attenuation artifacts from infarcts [8], although CT is becoming increasingly useful for these indications. Wall motion abnormalities and ejection fraction have been shown to be independent predictors of the extent of CAD [12,13]. However, stress myocardial perfusion scintigraphy is generally the preferred method for identifying regional ischemia, and stress RNV is not usually necessary if an adequate perfusion study has been obtained. In the presence of a positive perfusion study, the stress RNV is superfluous.

In patients with typical angina (high pretest likelihood of disease), stress perfusion or RNV studies are useful for estimating the extent (single-vessel versus multi-vessel disease) and severity of coronary stenosis, which has relevance for prognosis, choice among therapeutic options, and advisability of performing coronary arteriography. In patients with atypical angina, stress perfusion imaging is useful for determining whether myocardial ischemia is the etiology.

Positron Emission Tomography

Myocardial PET imaging with ^{82}Rb, fluro-deoxy glucose (FDG), and ^{13}N is now reimbursable by the Center for Medicaid and Medicare Services, underscoring recent technology advances. The coincidence detection method used in PET imaging allows for reliable correction of the problems associated with nonuniform attenuation of photons in the chest and for differences between men and women [14]. In a meta-analysis of 8 studies with 791 patients evaluated for CAD by PET, a combined sensitivity and specificity were determined to be 93% and 92%, respectively [15]. In the same article, three studies comparing Tl-201 single-proton-emission computed tomography (SPECT) and Rb-82 or NH3 PET were analyzed, and the overall accuracy of PET was 91%, compared to 81% for Tl-201 SPECT. It also may be the case that the sensitivity of PET can be increased when it is performed with CT [16].

Echocardiography

Stress 2-dimensional (2-D) echo is increasingly used for patients with suspected regional wall motion abnormalities produced by regional ischemia, in part because of the ubiquity of 2-D echocardiography. Technical limitations associated with exercise stress can be overcome by using pharmacological (dobutamine) stress. A recent meta-analysis of 44 studies indicated that stress echocardiography has a similar sensitivity to stress SPECT (85% and 87%, respectively) with a higher specificity (77% vs 64%) [17]. This technique is limited by the fact that it sometimes yields nondiagnostic results and that suboptimal definition of some regions of the left ventricle can lead to subjective interpretation Resting echocardiography can be useful if pericardial effusion or valvular or chamber abnormalities are suspected.

Transesophageal echocardiography is generally not indicated for evaluating chronic angina. The expense of this study does not justify its use in this setting. Although it is sometimes used for assessing aortic pathology (eg, dissection, aneurysm, and penetrating ulcer) in patients with chronic chest pain, CT and MRI are less invasive and simpler to perform.

Computed Tomography

Electron beam (ultrafast) CT (EBCT) can detect the presence and severity of calcification, a sign of coronary atherosclerosis [18-22]. EBCT is very sensitive for significant atherosclerotic disease, but many coronary lesions are eccentric and do not decrease the luminal diameter; therefore the presence of calcification is not specific for stenosis. A meta-analysis of 9 studies and 1662 subjects calculated a pooled sensitivity and specificity of 92.3% and 51.2%, respectively, for ≥50% stenosis [23]. The absence of coronary arterial calcification (CAC) in patients with chronic angina makes significant coronary obstructive disease unlikely (less than 1% [24]) but does not exclude it. Similarly, the presence of 3-vessel disease and/or extensive calcification (eg, a high calcium score) confers a high likelihood of coronary obstructive disease, but it does not confirm the diagnosis.

Because of the limitations described above, at present no CT vendor manufactures commercial EBCT units, and support for units currently in use is becoming scarce. Research focused on the relative equivalence of EBCT and MDCT with submillimeter spatial resolution and high temporal resolution has demonstrated agreement between coronary calcium scores [25-27], despite early reports of poor correlation with older CT technology [28].

Calcium scoring (noncontrast ECG-gated MDCT) is controversial. On one hand, the test is relatively inexpensive, and absence of coronary calcification is useful evidence against myocardial ischemia [18]. In a large study of 10,377 subjects it has been shown that coronary calcium score provides independent incremental information in addition to traditional risk factors in the prediction of all cause mortality [29]. On the other hand, patients who present with chronic chest pain of suspected cardiac origin are typically older, with a significant proportion over 60 years old. Because coronary calcium is so prevalent in this population, a "positive" score, even in the upper quartiles, cannot be used as strong evidence of myocardial ischemia.

There is also significantly greater use of coronary CT angiography (CTA) (specifically, contrast enhanced ECG-gated MDCT) to evaluate for CAD. Over the past 5 years, CT vendors have increased the number of detectors (from 4 to 64 and, with experimental human results, up to 256), improved the spatial resolution to submillimeter, and decreased the temporal resolution to approximately 0.1 second. While these improvements have not equaled catheter-based coronary angiography, recent studies have shown a high sensitivity of MDCT for treatable stenoses of the coronary arteries [30-32]. Using present

technology, the major strength of coronary CTA is its high negative predictive value (in comparison with the positive predictive value), and thus it suffers the same limitations as calcium scoring. It should be noted that the utility of coronary CTA becomes limited in more elderly patients (ie, those with a high burden of calcium) who have a pretest probability of CAD. Namely, the population of patients who present with chronic chest pain typically have CAD, and thus excluding a hemodynamically significant stenosis may be challenging. In patients who are younger and who have a lower pretest probability of CAD, coronary CTA can exclude a coronary etiology of chronic chest pain. Moreover, CT can exclude 3-vessel disease potentially missed by nuclear imaging (eg, so-called "balanced" ischemia) in patients with a high clinical suspicion of CAD.

There are other indications for which CT is the imaging test of choice, specifically aortic disease (aortic dissection, penetrating aortic ulcer, etc) and pulmonary embolism. CT has the advantage that it detects, with high specificity, a large number of extracardiac diagnoses.

Magnetic Resonance Imaging

Use of MRI for evaluating cardiac anatomy, valvular disease, certain cardiomyopathies, viability, and cardiac function continues to evolve. Protocols for measuring myocardial perfusion and angiography of the pulmonary and systemic vessels have matured significantly in the past few years. Magnetic resonance angiography (MRA) of the coronary arteries is still problematic due to their small size and incessant motion tied to the respiratory and cardiac cycles. At this time, MRA should be limited to sites with extensive experience and appropriate hardware and software to exclude disease in the proximal coronary arteries. At present, only CTA can noninvasively visualize coronary arteries on a routine basis.

MRI myocardial perfusion can be used to assess for significant CAD. First pass perfusion, rest perfusion, and stress perfusion protocols have been developed and validated; these are equivalent to and in some cases reported superior to SPECT [33-35]. High-dose dobutamine stress cardiac MRI has also been used in patients with poor acoustic windows which would have otherwise limited the utility of stress echocardiography [36] and has been shown to have a higher diagnostic accuracy than dobutamine stress echocardiography [37]. However, MRI is difficult to use, as most patients with pacemakers or implanted cardiac defibrillators are prohibited from obtaining a study and some other patients are too claustrophobic to tolerate an examination that routinely requires up to 60 minutes. While MRI is significantly more expensive than other studies that provide similar information, it can be used as a problem-solving tool for patients who can benefit from the high image contrast inherent in the myocardium and blood interface.

Invasive Techniques

Catheter-based angiography remains the coronary imaging modality with the highest spatial and temporal resolution. Thus, despite the fact that only projection images are obtained (as opposed to 3D volumes in CT), catheter-based angiography is considered by most to be the "gold-standard" for depicting the anatomy and the severity of obstructive CAD and other coronary arterial abnormalities (such as spasm) [38]. Moreover, it is needed to guide transluminal interventions. There is no general agreement regarding its use in patients with angina, but it is clearly not indicated in all patients who present with chronic chest pain. There is evidence that this test may be over utilized [39].

There remains agreement that catheter-based angiography is indicated in patients in whom angina is not adequately managed by vigorous medical therapy and in those in whom left main stenosis or severe multivessel disease is suggested by results of nuclear perfusion imaging. Left ventricular catheterization and left ventriculography are generally indicated, but not always necessary, to define ventricular function in patients with angina. In many patients, left ventricular function can be evaluated adequately using noninvasive studies (echocardiography and RNV).

Other Studies

Neither ultrasound nor nuclear imaging of the biliary system is usually indicated in patients who present with typical angina. However, patients who fall under the category of "chronic chest pain" can have a variety of diagnoses, and intermittent biliary obstruction from a gallstone can mimic intermittent pain from CAD. With respect to the "chronic" patient, a similar argument can be made for gastroesophageal reflux, and a fluoroscopy-based esophagram with or without an upper GI study, or endoscopic evaluation of the esophagus, can be obtained when symptoms are not classic for pain of a cardiac origin, or when the patient does not respond to standard therapy.

Summary

The defined approach to evaluation of the patient with chronic chest pain of probable cardiac origin is supported by a substantial body of literature. For patients with 1) a classic history and physical examination and 2) expected response to moderate medical therapy, no imaging study may be needed. Otherwise, stress nuclear imaging is used as a front-line modality to establish the diagnosis and assess the severity of myocardial ischemia. Based on the results of nuclear perfusion and/or clinical response to medical therapy, the next procedure is usually coronary angiography, with or without cardiac catheterization, and/or left ventriculography. Given the underlying prevalence of CAD in this patient population, the substitution of newer examinations (eg, CT and stress echocardiography) is promising but at present is not justified by current data; this outlook could change based on results of comparative studies and cost analysis.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because

there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations	
Relative Radiation Level	**Effective Dose Estimate Range**
None	0
Minimal	< 0.1 mSv
Low	0.1-1 mSv
Medium	1-10 mSv
High	10-100 mSv

Supporting Document(s)

- ACR Appropriateness Criteria® Overview
- Evidence table under review

References

1. Margolis JR, Chen JT, Kong Y, Peter RH, Behar VS, Kisslo JA. The diagnostic and prognostic significance of coronary artery calcification. A report of 800 cases. *Radiology* 1980; 137(3):609-616.
2. Basu S, Senior R, Dore C, Lahiri A. Value of thallium-201 imaging in detecting adverse cardiac events after myocardial infarction and thrombolysis: a follow up of 100 consecutive patients. *BMJ* 1996; 313(7061):844-848.
3. Bax JJ, Poldermans D, Elhendy A, Boersma E, Rahimtoola SH. Sensitivity, specificity, and predictive accuracies of various noninvasive techniques for detecting hibernating myocardium. *Curr Probl Cardiol* 2001; 26(2):147-186.
4. Beller GA. Diagnostic accuracy of thallium-201 myocardial perfusion imaging. *Circulation* 1991; 84(3 Suppl):I1-6.
5. Christian TF, Miller TD, Bailey KR, Gibbons RJ. Noninvasive identification of severe coronary artery disease using exercise tomographic thallium-201 imaging. *Am J Cardiol* 1992; 70(1):14-20.
6. Gibbons RJ. Rest and exercise radionuclide angiography for diagnosis in chronic ischemic heart disease. *Circulation* 1991; 84(3 Suppl):I93-99.
7. Giri S, Shaw LJ, Murthy DR, et al. Impact of diabetes on the risk stratification using stress single-photon emission computed tomography myocardial perfusion imaging in patients with symptoms suggestive of coronary artery disease. *Circulation* 2002; 105(1):32-40.
8. Meine TJ, Hanson MW, Borges-Neto S. The additive value of combined assessment of myocardial perfusion and ventricular function studies. *J Nucl Med* 2004; 45(10):1721-1724.
9. Soman P, Taillefer R, DePuey EG, Udelson JE, Lahiri A. Enhanced detection of reversible perfusion defects by Tc-99m sestamibi compared to Tc-99m tetrofosmin during vasodilator stress SPECT imaging in mild-to-moderate coronary artery disease. *J Am Coll Cardiol* 2001; 37(2):458-462.
10. Taillefer R, DePuey EG, Udelson JE, Beller GA, Latour Y, Reeves F. Comparative diagnostic accuracy of Tl-201 and Tc-99m sestamibi SPECT imaging (perfusion and ECG-gated SPECT) in detecting coronary artery disease in women. *J Am Coll Cardiol* 1997; 29(1):69-77.
11. Vanzetto G, Ormezzano O, Fagret D, Comet M, Denis B, Machecourt J. Long-term additive prognostic value of thallium-201 myocardial perfusion imaging over clinical and exercise stress test in low to intermediate risk patients: study in 1137 patients with 6-year follow-up. *Circulation* 1999; 100(14):1521-1527.
12. Borges-Neto S, Shaw LJ, Kesler KL, et al. Prediction of severe coronary artery disease by combined rest and exercise radionuclide angiocardiography and tomographic perfusion imaging with technetium 99m-labeled sestamibi: a comparison with clinical and electrocardiographic data. *J Nucl Cardiol* 1997; 4(3):189-194.
13. Palmas W, Friedman JD, Diamond GA, Silber H, Kiat H, Berman DS. Incremental value of simultaneous assessment of myocardial function and perfusion with technetium-99m sestamibi for prediction of extent of coronary artery disease. *J Am Coll Cardiol* 1995; 25(5):1024-1031.
14. Eisner R, Patterson R. Differences between women and men in the heterogenecity of myocardial perfusion images: SPECT, Tl-201, Tc-99m sestamibi, and PET Rb-82. *J Nucl Cardiol* 1997; 1(Part 2):S104.
15. Machac J. Cardiac positron emission tomography imaging. *Semin Nucl Med* 2005; 35(1):17-36.
16. Namdar M, Hany TF, Koepfli P, et al. Integrated PET/CT for the assessment of coronary artery disease: a feasibility study. *J Nucl Med* 2005; 46(6):930-935.
17. Fleischmann KE, Hunink MG, Kuntz KM, Douglas PS. Exercise echocardiography or exercise SPECT imaging? A meta-analysis of diagnostic test performance. *JAMA* 1998; 280(10):913-920.
18. Agatston AS, Janowitz WR, Hildner FJ, Zusmer NR, Viamonte M, Jr., Detrano R. Quantification of coronary artery calcium using ultrafast computed tomography. *J Am Coll Cardiol* 1990; 15(4):827-832.
19. Agatston AS, Janowitz WR, Kaplan G, Gasso J, Hildner F, Viamonte M, Jr. Ultrafast computed tomography-detected coronary calcium reflects the angiographic extent of coronary arterial atherosclerosis. *Am J Cardiol* 1994; 74(12):1272-1274.
20. Breen JF, Sheedy PF, 2nd, Schwartz RS, et al. Coronary artery calcification detected with ultrafast CT as an indication of coronary artery disease. *Radiology* 1992; 185(2):435-439.
21. Fallavollita JA, Brody AS, Bunnell IL, Kumar K, Canty JM, Jr. Fast computed tomography detection of coronary calcification in the diagnosis of coronary artery disease. Comparison with angiography in patients < 50 years old. *Circulation* 1994; 89(1):285-290.
22. Wong ND, Vo A, Abrahamson D, Tobis JM, Eisenberg H, Detrano RC. Detection of coronary artery calcium by ultrafast computed tomography and its relation to clinical evidence of coronary artery disease. *Am J Cardiol* 1994; 73(4):223-227.
23. Nallamothu BK, Saint S, Bielak LF, et al. Electron-beam computed tomography in the diagnosis of coronary artery disease: a meta-analysis. *Arch Intern Med* 2001; 161(6):833-838.
24. Haberl R, Becker A, Leber A, et al. Correlation of coronary calcification and angiographically documented stenoses in patients with suspected coronary artery disease: results of 1,764 patients. *J Am Coll Cardiol* 2001; 37(2):451-457.
25. Carr JJ, Crouse JR, 3rd, Goff DC, Jr., D'Agostino RB, Jr., Peterson NP, Burke GL. Evaluation of subsecond gated helical CT for quantification of coronary artery calcium and comparison with electron beam CT. *AJR* 2000; 174(4):915-921.
26. Detrano RC, Anderson M, Nelson J, et al. Coronary calcium measurements: effect of CT scanner type and calcium measure on rescan reproducibility--MESA study. *Radiology* 2005; 236(2):477-484.
27. Stanford W, Thompson BH, Burns TL, Heery SD, Burr MC. Coronary artery calcium quantification at multi-detector row helical CT versus electron-beam CT. *Radiology* 2004; 230(2):397-402.
28. Becker CR, Jakobs TF, Aydemir S, et al. Helical and single-slice conventional CT versus electron beam CT for the quantification of coronary artery calcification. *AJR* 2000; 174(2):543-547.
29. Shaw LJ, Raggi P, Schisterman E, Berman DS, Callister TQ. Prognostic value of cardiac risk factors and coronary artery calcium screening for all-cause mortality. *Radiology* 2003; 228(3):826-833.
30. Fine JJ, Hopkins CB, Hall PA, Delphia RE, Attebery TW, Newton FC. Noninvasive coronary angiography: agreement of multi-slice spiral computed tomography and selective catheter angiography. *Int J Cardiovasc Imaging* 2004; 20(6):549-552.
31. Nieman K, Cademartiri F, Lemos PA, Raaijmakers R, Pattynama PM, de Feyter PJ. Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. *Circulation* 2002; 106(16):2051-2054.

32. Ropers D, Baum U, Pohle K, et al. Detection of coronary artery stenoses with thin-slice multi-detector row spiral computed tomography and multiplanar reconstruction. *Circulation* 2003; 107(5):664-666.
33. Ibrahim T, Nekolla SG, Schreiber K, et al. Assessment of coronary flow reserve: comparison between contrast-enhanced magnetic resonance imaging and positron emission tomography. *J Am Coll Cardiol* 2002; 39(5):864-870.
34. Keijer JT, van Rossum AC, van Eenige MJ, et al. Magnetic resonance imaging of regional myocardial perfusion in patients with single-vessel coronary artery disease: quantitative comparison with (201)Thallium-SPECT and coronary angiography. *J Magn Reson Imaging* 2000; 11(6):607-615.
35. Wilke NM, Jerosch-Herold M, Zenovich A, Stillman AE. Magnetic resonance first-pass myocardial perfusion imaging: clinical validation and future applications. *J Magn Reson Imaging* 1999; 10(5):676-685.
36. Hundley WG, Hamilton CA, Thomas MS, et al. Utility of fast cine magnetic resonance imaging and display for the detection of myocardial ischemia in patients not well suited for second harmonic stress echocardiography. *Circulation* 1999; 100(16):1697-1702.
37. Nagel E, Lehmkuhl HB, Bocksch W, et al. Noninvasive diagnosis of ischemia-induced wall motion abnormalities with the use of high-dose dobutamine stress MRI: comparison with dobutamine stress echocardiography. *Circulation* 1999; 99(6):763-770.
38. Alderman EL, Corley SD, Fisher LD, et al. Five-year angiographic follow-up of factors associated with progression of coronary artery disease in the Coronary Artery Surgery Study (CASS). CASS Participating Investigators and Staff. *J Am Coll Cardiol* 1993; 22(4):1141-1154.
39. Graboys TB, Biegelsen B, Lampert S, Blatt CM, Lown B. Results of a second-opinion trial among patients recommended for coronary angiography. *JAMA* 1992; 268(18):2537-2540.

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.