

**American College of Radiology  
ACR Appropriateness Criteria®**

**Clinical Condition:**                      **Acute Nonspecific Chest Pain — Low Probability of Coronary Artery Disease**

Radiologic Procedure	Rating	Comments	<u>RRL*</u>
X-ray chest	9		⊕
CTA coronary arteries with contrast	7		⊕⊕⊕⊕
CTA coronary arteries with contrast with advanced low dose techniques	7		⊕⊕⊕
CTA chest (noncoronary) with contrast	7		⊕⊕⊕
US echocardiography transthoracic resting	7		○
SPECT MPI rest and stress	6		⊕⊕⊕⊕
Tc-99m V/Q scan lung	5		⊕⊕⊕
MRA aorta without and with contrast	5	See statement regarding contrast in text under “Anticipated Exceptions.”	○
X-ray rib views	5		⊕⊕⊕
MRA chest (noncoronary) without and with contrast	5	See statement regarding contrast in text under “Anticipated Exceptions.”	○
MRA aorta without contrast	4		○
MRA chest (noncoronary) without contrast	4		○
X-ray barium swallow and upper GI series	4		⊕⊕⊕
X-ray thoracic spine	4		⊕⊕⊕
US abdomen	4		○
MRI heart with or without stress without and with contrast	3		○
MRA pulmonary arteries without and with contrast	3		○
MRA coronary arteries without contrast	3		○
MRA coronary arteries without and with contrast	3		○
US echocardiography transthoracic stress	3		○
US echocardiography transesophageal	2		○
MRI heart with or without stress without contrast	2		○
MRA pulmonary arteries without contrast	2		○
Coronary angiography with or without ventriculography	1		⊕⊕⊕
<b>Rating Scale:</b> 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			<b>*Relative Radiation Level</b>

# ACUTE NONSPECIFIC CHEST PAIN — LOW PROBABILITY OF CORONARY ARTERY DISEASE

Expert Panel on Cardiac Imaging: Udo Hoffman, MD<sup>1</sup>; Vikram Venkatesh, MD<sup>2</sup>; Richard D. White, MD<sup>3</sup>; Pamela K. Woodard, MD<sup>4</sup>; J. Jeffrey Carr MD, MSCE<sup>5</sup>; Sharmila Dorbala, MD<sup>6</sup>; James P. Earls, MD<sup>7</sup>; Jill E. Jacobs, MD<sup>8</sup>; Leena Mammen, MD<sup>9</sup>; Edward T. Martin, III, MD<sup>10</sup>; Thomas Ryan, MD<sup>11</sup>; Charles S. White, MD.<sup>12</sup>

## Summary of Literature Review

Patients who present to the emergency department (ED) with acute chest pain are stratified according to their probability of developing acute coronary syndrome (ACS) as follows: very low (<1%), low (1%-4%), intermediate (4%-8%), or high (>8%) probability. This document outlines the usefulness of available diagnostic imaging for those patients without known coronary artery disease (CAD) and at low probability for having CAD who do not present with classic ACS signs, symptoms, or electrocardiogram (ECG) abnormalities, but rather with nonspecific chest pain leading to a differential diagnosis, including pulmonary, gastrointestinal (GI), or musculoskeletal pathologies [1-2]. In contrast, patients presenting to the ED with signs and/or symptoms [3] of ACS along with diagnostic ST-segment changes, and elevated cardiac enzymes suggesting myocardial infarction [4] are not included in this discussion as the evaluation and treatment algorithms have been well defined in the Scientific Statements and Practice Guidelines of the American Heart Association [5] and in the ACR Appropriateness Criteria<sup>®</sup> topic “[Chest Pain, Suggestive of Acute Coronary Syndrome](#).”

The following imaging modalities are available in evaluating patients presenting to the ED with low probability of CAD: chest radiography, multidetector computed tomography (MDCT), magnetic resonance imaging (MRI), ventilation/perfusion (V/Q) scans, cardiac perfusion scintigraphy, transesophageal and transthoracic echocardiography, positron emission tomography (PET),

spine and rib radiography, barium esophageal and upper GI studies, and abdominal ultrasound [6-7].

## Chest Radiography

The chest radiograph is the recommended initial imaging study [8]. Chest radiographs can help identify potential sources of previously undifferentiated chest pain such as pneumothorax, pneumomediastinum, fractured ribs, acute and chronic infections, and malignancies. Other conditions producing chest pain, such as pulmonary emboli (PE), may be suspected from the chest radiograph, but the overall sensitivities are low [9]. Thoracic calcifications, if present, may indicate pericardial disease, ventricular aneurysm, intracardiac thrombi, or aortic disease. While chest radiographs are often normal for the presence of PE, the presence of a Hampton hump, Westermark sign, or pulmonary artery enlargement may suggest PE [10]. Mediastinal air may indicate a ruptured viscus or subpleural bleb or other acute pathology.

## Multidetector Computed Tomography

MDCT has excellent accuracy in demonstrating noncardiac causes of chest pain, including pneumothorax, pneumonia, malignancies, pulmonary airspace abnormalities, and interstitial lung disease. Pericardial effusions, thickening, and/or calcifications are seen far more readily than with radiographs alone [11-14]. In the setting of undifferentiated chest pain, CT angiography (CTA) with its high sensitivity and specificity can be considered the modality of choice to diagnose suspected PE and/or aortic pathology such as aortic dissection (AD) or aneurysm [15-18]. Both prospectively (mean radiation exposure <5 mSv) and retrospectively (mean radiation exposure <12 mSv) ECG-synchronized cardiac CT permits comprehensive assessment of the presence and extent of CAD [19-20]. Most importantly, in this low-risk population, cardiac CTA has nearly perfect negative predictive value to rule out significant CAD [21-24]. When coronary CTA is performed with retrospective ECG gating, additional assessment of wall motion adds significant incremental value [25]. MDCT is also the primary method for diagnosing coronary anomalies, a rare cause of acute chest pain [26-28].

Cardiac CT can also detect other symptom-producing pathologies such as ventricular aneurysms and cardiac thrombi or tumors [29]. Significant findings such as PE or AD appear to be rare in patients with undifferentiated chest pain, probably because of the low probability for any disease. However, pulmonary nodules are detected in a significant number of patients [30]. With advanced CT technology, it is possible to perform a single-phase triple rule-out examination allowing comprehensive assessment of CAD, AD, and PE [31-33]. However, its efficiency or effectiveness has not been demonstrated.

<sup>1</sup>Principal Author, Massachusetts General Hospital, Boston, Massachusetts.

<sup>2</sup>Research Author, Massachusetts General Hospital, Boston, Massachusetts.

<sup>3</sup>Panel Chair, Ohio State University College of Medicine, Columbus, Ohio.

<sup>4</sup>Panel Vice-chair, Mallinckrodt Institute of Radiology, Washington University School of Medicine, Saint Louis, Missouri.

<sup>5</sup>Wake Forest University Health Sciences, Winston Salem, North Carolina.

<sup>6</sup>Brigham and Women's Hospital, Boston, Massachusetts, Society of Nuclear Medicine.

<sup>7</sup>Fairfax Radiological Consultants, Fairfax, Virginia.

<sup>8</sup>New York University Medical Center, New York, New York.

<sup>9</sup>Advanced Radiology Services, Grand Rapids, Michigan.

<sup>10</sup>Oklahoma Heart Institute, Tulsa, Oklahoma, American College of Cardiology.

<sup>11</sup>The Ohio State University Heart and Vascular Center, Columbus, Ohio, American College of Cardiology.

<sup>12</sup>University of Maryland Hospital, Baltimore, Maryland.

The American College of Radiology seeks and encourages collaboration with other organizations on the development of the ACR Appropriateness Criteria through society representation on expert panels. Participation by representatives from collaborating societies on the expert panel does not necessarily imply individual or society endorsement of the final document.

Reprint requests to: Department of Quality & Safety, American College of Radiology, 1891 Preston White Drive, Reston, VA 20191-4397.

Recent advances in cardiac CT imaging technology allow for further reduction of the radiation dose from cardiac CTA [34]; available new dose-reducing techniques include prospective triggering [35-37], adaptive statistical iterative reconstruction [38], and high-pitch spiral acquisition [39]. These new lower-dose techniques are the appropriate choice in properly selected patients who have a low heart rate (<65 bpm) and are in sinus rhythm.

### **Transthoracic and Transesophageal Echocardiography**

Transthoracic and transesophageal echocardiography, with or without pharmacologic stress, are frequently used to define abnormalities of ventricular wall motion as an indicator of cardiac disease [40]. In addition, echocardiography can readily demonstrate pericardial effusion, valve dysfunction, and cardiac thrombus. Aortic pathology can be identified [41-42], but the findings of intramural hematoma, dissection, pulmonary embolus, and aneurysm are better seen with MDCT or MRI. Most importantly, transthoracic echocardiography without stress is a low-risk screening examination with high negative predictive value for ACS.

### **Magnetic Resonance Imaging**

Magnetic resonance angiography (MRA) can be performed with either noncontrast (eg, time-of-flight, balanced steady-state free precession, phase-contrast, black-blood) or contrast-enhanced (eg, 3D arterial-phase fast gradient-echo) protocols that are useful in identifying vascular pathology. These techniques can be used to accurately identify aortic pathology and in specific scenarios may also be used to evaluate for pulmonary artery pathology [43-44]. MRA is typically more time-consuming and less available in the ED setting, but it is an important alternative noninvasive imaging strategy in patients with a contraindication to CTA. Cardiac MRI has not been well studied in low-risk undifferentiated chest pain populations and is uncommonly used in the emergency setting because of the relatively long scan times. The benefits and role of cardiac MRI, both with and without pharmacologic stress, in this population remain uncertain and have yet to be subjected to large controlled trials [45-47].

### **Radiography of the Ribs, Cervical Spine, or Thoracic Spine**

Rib or spine radiographs are indicated in patients with a clinical suspicion of skeletal pathology.

### **Radionuclide Studies**

*Radionuclide myocardial perfusion studies at rest but more typically at stress* with thallium 201, technetium 99m sestamibi, or tetrofosmin are frequently used in identifying perfusion abnormalities as an indicator of ischemic chest pain, especially when a cardiac etiology is suspected [48-54]. A normal stress perfusion scan may be used to exclude the diagnosis of CAD in patients in whom myocardial infarction by enzymes has been ruled out.

*PET* is an alternative method for evaluating myocardial perfusion deficits, using N-13 ammonia or rubidium 82

agents. However, PET is not indicated in low probability patients.

*V/Q lung scintigraphy* can be used in patients with clinically suspected PE, but this study has been largely replaced by MDCT.

### **Cardiac Catheterization**

Cardiac catheterization with coronary digital subtraction angiography remains the gold standard in demonstrating CAD and can permit immediate therapeutic intervention. However, there is rarely an indication to use it in low-probability patients, because the high negative predictive value of coronary CTA enables it to be used alone to exclude CAD.

### **Barium Swallow or Endoscopy**

Esophageal disorders can be the cause of chest pain. A water-soluble or barium contrast upper GI swallowing study or endoscopy may be helpful in establishing esophageal spasm or reflux as an etiology of the chest pain [55].

### **Abdominal Ultrasonography**

Abdominal ultrasound may be indicated to document cholecystitis as a cause for the chest pain. Ultrasound is also helpful in evaluating pancreatitis, other solid-organ pathology at and/or intra-abdominal abscesses and fluid collections and less frequently GI pathology.

### **Summary**

- This document applies to patients at low risk for CAD who present with undifferentiated chest pain and without signs of ischemia in which a chest radiograph is almost universally obtained.
- Cardiac CT, as well as, rest and stress SPECT MPI, owing to its high negative predictive value, is increasingly used in the evaluation of coronary disease in this population and may be incorporated into the workup algorithm of those with low-probability chest pain.
- Chest CT and transthoracic echocardiography play an important role in evaluating noncoronary or consequences of coronary causes of chest pain.
- A number of diagnostic tests, among them ultrasound of the abdomen, MRA of the aorta with or without contrast, x-ray rib views, x-ray barium swallow, and upper GI series may also be appropriate to use in evaluating noncardiac causes of chest pain.
- Typically, more invasive imaging tests such as transesophageal echocardiography or coronary angiography as well as advanced specific cardiac MRI examinations are rarely indicated in diagnosing low risk nonspecific chest pain.

### **Anticipated Exceptions**

Nephrogenic systemic fibrosis (NSF) is a disorder with a scleroderma-like presentation and a spectrum of manifestations that can range from limited clinical sequelae to fatality. It appears to be related to both underlying severe renal dysfunction and the

administration of gadolinium-based contrast agents. It has occurred primarily in patients on dialysis, rarely in patients with very limited glomerular filtration rate (GFR) (ie, <30 mL/min/1.73m<sup>2</sup>), and almost never in other patients. There is growing literature regarding NSF. Although some controversy and lack of clarity remain, there is a consensus that it is advisable to avoid all gadolinium-based contrast agents in dialysis-dependent patients unless the possible benefits clearly outweigh the risk, and to limit the type and amount in patients with estimated GFR rates <30 mL/min/1.73m<sup>2</sup>. For more information, please see the [ACR Manual on Contrast Media](#) [56].

### 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. Patients in the pediatric age group are at inherently higher risk from exposure, both because of organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared to those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria<sup>®</sup> [Radiation Dose Assessment Introduction](#) document.

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
⊕	<0.1 mSv	<0.03 mSv
⊕⊕	0.1-1 mSv	0.03-0.3 mSv
⊕⊕⊕	1-10 mSv	0.3-3 mSv
⊕⊕⊕⊕	10-30 mSv	3-10 mSv
⊕⊕⊕⊕⊕	30-100 mSv	10-30 mSv

\*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as NS (not specified).

### Supporting Document(s)

- [ACR Appropriateness Criteria<sup>®</sup> Overview](#)
- [Procedure Information](#)
- [Evidence Table](#)

### References

1. Hutter AM. Chest pain: how to distinguish between cardiac and noncardiac causes. Interview by Eric R. Leibovitch. *Geriatrics* 1995; 50(9):32-36, 39-40.
2. Solinas L, Raucci R, Terrazzino S, et al. Prevalence, clinical characteristics, resource utilization and outcome of patients with acute chest pain in the emergency department. A multicenter, prospective, observational study in north-eastern Italy. *Ital Heart J* 2003; 4(5):318-324.
3. Clinical policy for the initial approach to adults presenting with a chief complaint of chest pain, with no history of trauma. American College of Emergency Physicians. *Ann Emerg Med* 1995; 25(2):274-299.
4. Antman EM, Hand M, Armstrong PW, et al. 2007 focused update of the ACC/AHA 2004 guidelines for the management of patients with ST-elevation myocardial infarction: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol* 2008; 51(2):210-247.
5. Scientific Statements and Practice Guidelines Topic List. <http://www.americanheart.org/presenter.jhtml?identifier=2158>. Accessed March 4, 2008.
6. Ioannidis JP, Salem D, Chew PW, Lau J. Accuracy of imaging technologies in the diagnosis of acute cardiac ischemia in the emergency department: a meta-analysis. *Ann Emerg Med* 2001; 37(5):471-477.
7. Jesse RL, Kontos MC. Evaluation of chest pain in the emergency department. *Curr Probl Cardiol* 1997; 22(4):149-236.
8. Buenger RE. Five thousand acute care/emergency department chest radiographs: comparison of requisitions with radiographic findings. *J Emerg Med* 1988; 6(3):197-202.
9. Elliott CG, Goldhaber SZ, Visani L, DeRosa M. Chest radiographs in acute pulmonary embolism. Results from the International Cooperative Pulmonary Embolism Registry. *Chest* 2000; 118(1):33-38.
10. Worsley DF, Alavi A, Aronchick JM, Chen JT, Greenspan RH, Ravin CE. Chest radiographic findings in patients with acute pulmonary embolism: observations from the PIOPED Study. *Radiology* 1993; 189(1):133-136.
11. Johnson TR, Nikolaou K, Wintersperger BJ, et al. ECG-gated 64-MDCT angiography in the differential diagnosis of acute chest pain. *AJR* 2007; 188(1):76-82.
12. Laudon DA, Vukov LF, Breen JF, Rumberger JA, Wollan PC, Sheedy PF, 2nd. Use of electron-beam computed tomography in the evaluation of chest pain patients in the emergency department. *Ann Emerg Med* 1999; 33(1):15-21.
13. Olivetti L, Mazza G, Volpi D, Costa F, Ferrari O, Pirelli S. Multislice CT in emergency room management of patients with chest pain and medium-low probability of acute coronary syndrome. *Radiol Med (Torino)* 2006; 111(8):1054-1063.
14. White CS, Kuo D, Kelemen M, et al. Chest pain evaluation in the emergency department: can MDCT provide a comprehensive evaluation? *AJR* 2005; 185(2):533-540.
15. Perrier A, Roy PM, Sanchez O, et al. Multidetector-row computed tomography in suspected pulmonary embolism. *N Engl J Med* 2005; 352(17):1760-1768.
16. Shiga T, Wajima Z, Apfel CC, Inoue T, Ohe Y. Diagnostic accuracy of transesophageal echocardiography, helical computed tomography, and magnetic resonance imaging for suspected thoracic aortic dissection: systematic review and meta-analysis. *Arch Intern Med* 2006; 166(13):1350-1356.
17. van Belle A, Buller HR, Huisman MV, et al. Effectiveness of managing suspected pulmonary embolism using an algorithm combining clinical probability, D-dimer testing, and computed tomography. *JAMA* 2006; 295(2):172-179.
18. Yoshida S, Akiba H, Tamakawa M, et al. Thoracic involvement of type A aortic dissection and intramural hematoma: diagnostic accuracy--comparison of emergency helical CT and surgical findings. *Radiology* 2003; 228(2):430-435.

19. Hoffmann U, Bamberg F. Is computed tomography coronary angiography the most accurate and effective noninvasive imaging tool to evaluate patients with acute chest pain in the emergency department?: CT coronary angiography is the most accurate and effective noninvasive imaging tool for evaluating patients presenting with chest pain to the emergency department. *Circ Cardiovasc Imaging* 2009; 2(3):251-263; discussion 263.
20. Schertler T, Glucker T, Wildermuth S, Jungius KP, Marincek B, Boehm T. Comparison of retrospectively ECG-gated and nongated MDCT of the chest in an emergency setting regarding workflow, image quality, and diagnostic certainty. *Emerg Radiol* 2005; 12(1-2):19-29.
21. Gallagher MJ, Ross MA, Raff GL, Goldstein JA, O'Neill WW, O'Neil B. The diagnostic accuracy of 64-slice computed tomography coronary angiography compared with stress nuclear imaging in emergency department low-risk chest pain patients. *Ann Emerg Med* 2007; 49(2):125-136.
22. Goldstein JA, Gallagher MJ, O'Neill WW, Ross MA, O'Neil BJ, Raff GL. A randomized controlled trial of multi-slice coronary computed tomography for evaluation of acute chest pain. *J Am Coll Cardiol* 2007; 49(8):863-871.
23. Hoffmann U, Nagurney JT, Moselewski F, et al. Coronary multidetector computed tomography in the assessment of patients with acute chest pain. *Circulation* 2006; 114(21):2251-2260.
24. Rubinshtein R, Halon DA, Gaspar T, et al. Usefulness of 64-slice cardiac computed tomographic angiography for diagnosing acute coronary syndromes and predicting clinical outcome in emergency department patients with chest pain of uncertain origin. *Circulation* 2007; 115(13):1762-1768.
25. Seneviratne SK, Truong QA, Bamberg F, et al. Incremental diagnostic value of regional left ventricular function over coronary assessment by cardiac computed tomography for the detection of acute coronary syndrome in patients with acute chest pain: from the ROMICAT trial. *Circ Cardiovasc Imaging* 2010; 3(4):375-383.
26. Hoffmann U, Pena AJ, Moselewski F, et al. MDCT in early triage of patients with acute chest pain. *AJR* 2006; 187(5):1240-1247.
27. Hollander JE, Litt HI, Chase M, Brown AM, Kim W, Baxt WG. Computed tomography coronary angiography for rapid disposition of low-risk emergency department patients with chest pain syndromes. *Acad Emerg Med* 2007; 14(2):112-116.
28. Schroeder S, Kuettner A, Beck T, et al. Usefulness of noninvasive MSCT coronary angiography as first-line imaging technique in patients with chest pain: initial clinical experience. *Int J Cardiol* 2005; 102(3):469-475.
29. Mochizuki T, Hosoi S, Higashino H, Koyama Y, Mima T, Murase K. Assessment of coronary artery and cardiac function using multidetector CT. *Semin Ultrasound CT MR* 2004; 25(2):99-112.
30. Lehman SJ, Abbara S, Cury RC, et al. Significance of cardiac computed tomography incidental findings in acute chest pain. *Am J Med* 2009; 122(6):543-549.
31. Mark DB, Berman DS, Budoff MJ, et al. ACCF/ACR/AHA/NASCI/SAIP/SCAI/SCCT 2010 expert consensus document on coronary computed tomographic angiography: a report of the American College of Cardiology Foundation Task Force on Expert Consensus Documents. *J Am Coll Cardiol* 2010; 55(23):2663-2699.
32. Savino G, Herzog C, Costello P, Schoepf UJ. 64 slice cardiovascular CT in the emergency department: concepts and first experiences. *Radiol Med* 2006; 111(4):481-496.
33. Takakuwa KM, Halpern EJ. Evaluation of a "triple rule-out" coronary CT angiography protocol: use of 64-Section CT in low-to-moderate risk emergency department patients suspected of having acute coronary syndrome. *Radiology* 2008; 248(2):438-446.
34. Gerber TC, Kantor B, McCollough CH. Radiation dose and safety in cardiac computed tomography. *Cardiol Clin* 2009; 27(4):665-677.
35. Earls JP, Berman EL, Urban BA, et al. Prospectively gated transverse coronary CT angiography versus retrospectively gated helical technique: improved image quality and reduced radiation dose. *Radiology* 2008; 246(3):742-753.
36. Husmann L, Valenta I, Gaemperli O, et al. Feasibility of low-dose coronary CT angiography: first experience with prospective ECG-gating. *Eur Heart J* 2008; 29(2):191-197.
37. Stolzmann P, Leschka S, Scheffel H, et al. Dual-source CT in step-and-shoot mode: noninvasive coronary angiography with low radiation dose. *Radiology* 2008; 249(1):71-80.
38. Leipsic J, Labounty TM, Heilbron B, et al. Estimated radiation dose reduction using adaptive statistical iterative reconstruction in coronary CT angiography: the ERASIR study. *AJR* 2010; 195(3):655-660.
39. Achenbach S, Marwan M, Ropers D, et al. Coronary computed tomography angiography with a consistent dose below 1 mSv using prospectively electrocardiogram-triggered high-pitch spiral acquisition. *Eur Heart J* 2010; 31(3):340-346.
40. Di Pasquale P, Cannizzaro S, Scalzo S, et al. Sensitivity, specificity and predictive value of the echocardiography and troponin-T test combination in patients with non-ST elevation acute coronary syndromes. *Int J Cardiovasc Imaging* 2004; 20(1):37-46.
41. Kontos MC, Arrowood JA, Paulsen WH, Nixon JV. Early echocardiography can predict cardiac events in emergency department patients with chest pain. *Ann Emerg Med* 1998; 31(5):550-557.
42. Lim SH, Sayre MR, Gibler WB. 2-D echocardiography prediction of adverse events in ED patients with chest pain. *Am J Emerg Med* 2003; 21(2):106-110.
43. Ersoy H, Goldhaber SZ, Cai T, et al. Time-resolved MR angiography: a primary screening examination of patients with suspected pulmonary embolism and contraindications to administration of iodinated contrast material. *AJR* 2007; 188(5):1246-1254.
44. Stein PD, Chenevert TL, Fowler SE, et al. Gadolinium-enhanced magnetic resonance angiography for pulmonary embolism: a multicenter prospective study (PIOPED III). *Ann Intern Med* 2010; 152(7):434-443, W142-433.
45. Cury RC, Shash K, Nagurney JT, et al. Cardiac magnetic resonance with T2-weighted imaging improves detection of patients with acute coronary syndrome in the emergency department. *Circulation* 2008; 118(8):837-844.
46. Ingkanisorn WP, Kwong RY, Bohme NS, et al. Prognosis of negative adenosine stress magnetic resonance in patients presenting to an emergency department with chest pain. *J Am Coll Cardiol* 2006; 47(7):1427-1432.
47. Kwong RY, Chan AK, Brown KA, et al. Impact of unrecognized myocardial scar detected by cardiac magnetic resonance imaging on event-free survival in patients presenting with signs or symptoms of coronary artery disease. *Circulation* 2006; 113(23):2733-2743.
48. Hackshaw BT. Excluding heart disease in the patient with chest pain. *Am J Med* 1992; 92(5A):46S-51S.
49. Hilton TC, Thompson RC, Williams HJ, Saylor R, Fulmer H, Stowers SA. Technetium-99m sestamibi myocardial perfusion imaging in the emergency room evaluation of chest pain. *J Am Coll Cardiol* 1994; 23(5):1016-1022.
50. Kontos MC, Jesse RL, Anderson FP, Schmidt KL, Ornato JP, Tatum JL. Comparison of myocardial perfusion imaging and cardiac troponin I in patients admitted to the emergency department with chest pain. *Circulation* 1999; 99(16):2073-2078.
51. Swinburn J, Lahiri A. Can nuclear cardiology really help in the emergency departments of the 21st century? *Rev Port Cardiol* 2000; 19 Suppl 1:147-52.
52. Udelson JE, Beshansky JR, Ballin DS, et al. Myocardial perfusion imaging for evaluation and triage of patients with suspected acute cardiac ischemia: a randomized controlled trial. *JAMA* 2002; 288(21):2693-2700.
53. Varetto T, Cantalupi D, Altieri A, Orlandi C. Emergency room technetium-99m sestamibi imaging to rule out acute myocardial ischemic events in patients with nondiagnostic electrocardiograms. *J Am Coll Cardiol* 1993; 22(7):1804-1808.
54. Williams KA, Garvin AA, Taillon LA. Clinical nuclear imaging techniques for the diagnosis and evaluation of acute myocardial infarction. *Compr Ther* 1992; 18(2):6-10.
55. Just RJ, Castell DO. Chest pain of undetermined origin. *Gastrointest Endosc Clin N Am* 1994; 4(4):731-746.
56. American College of Radiology. *Manual on Contrast Media*. Available at: [http://www.acr.org/SecondaryMainMenuCategories/quality\\_safety/contrast\\_manual.aspx](http://www.acr.org/SecondaryMainMenuCategories/quality_safety/contrast_manual.aspx).

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.