

2015 ACR/ACC/AHA/AATS/ACEP/ASNC/NASCI/SAEM/SCCT/SCMR/SCPC/SNMMI/STR/STS Appropriate Utilization of Cardiovascular Imaging in Emergency Department Patients With Chest Pain

A Joint Document of the American College of Radiology Appropriateness Criteria Committee and the American College of Cardiology Appropriate Use Criteria Task Force

Emergency Department Patients With Chest Pain Writing Panel:

Frank J. Rybicki, MD, PhD, Co-Chair^{a,1,2}, James E. Udelson, MD, Co-Chair^b,
W. Frank Peacock, MD, Co-Chair^c, Samuel Z. Goldhaber, MD^b, Eric M. Isselbacher, MD^b,
Ella Kazerooni, MD^a, Michael C. Kontos, MD^b, Harold Litt, MD, PhD^a, Pamela K. Woodard, MD^a

Emergency Department Patients With Chest Pain Rating Panel: Joseph S. Alpert, MD^d,
George A. Andrews, MD, MBA, CPE^e, Edward P. Chen, MD^f, David T. Cooke, MD^g,
Ricardo C. Cury, MD^b, Daniel Edmundowicz, MDⁱ, Victor Ferrari, MD^j, Louis G. Graff, MD^k,
Judd E. Hollander, MD^l, Lloyd W. Klein, MD^a, Jonathan Leipsic, MD^m, Phillip D. Levy, MD, MPHⁿ,
John J. Mahmorian, MD^o, Craig Rosenberg, MD^p, Geoffrey Rubin, MD^a, R. Parker Ward, MD^q,
Charles White, MD^r

Appropriate Utilization of Cardiovascular Imaging Oversight Committee:

ACR E. Kent Yucel, MD, FACR, Co-Chair^a, J. Jeffrey Carr, MD, MSc, FACR^a,
Frank J. Rybicki, MD, PhD, FACR^a, Richard D. White, MD, FACR^a, Pamela K. Woodard, MD, FACR^a,
ACC Manesh Patel, MD, FACC, Co-Chair^b, Pamela Douglas, MD, MACC^b, Robert C. Hendel, MD, FACC^b,
Christopher Kramer, MD, FACC^b, John Doherty, MD, FACC^b

Key Words: ACC appropriate use criteria, ACR Appropriateness Criteria, appropriate utilization, chest pain, imaging, multimodality
J Am Coll Radiol 2016; ■:■-■. © 2016 by the American College of Cardiology Foundation and the American College of Radiology

^aOfficial American College of Radiology Representative.

^bOfficial American College of Cardiology Representative.

^cOfficial American College of Emergency Physicians Representative.

^dOfficial American Heart Association Representative.

^eOfficial Payer, Humana Representative.

^fOfficial American Association for Thoracic Surgery Representative.

^gOfficial Society of Thoracic Surgeons Representative.

^hOfficial Society of Cardiovascular Computed Tomography Representative.

ⁱOfficial Society of Atherosclerosis Imaging and Prevention Representative.

^jOfficial Society for Cardiovascular Magnetic Resonance Representative.

^kOfficial American College of Emergency Physicians Representative.

^lOfficial Society for Academic Emergency Medicine Representative.

^mOfficial North American Society for Cardiovascular Imaging Representative.

ⁿOfficial Society for Cardiovascular Patient Care Representative.

^oOfficial American Society of Nuclear Cardiology Representative.

^pOfficial American College of Physicians Representative. Dr. Rosenberg's representation does not imply ACP endorsement of this guideline.

^qOfficial American Society of Echocardiography Representative. Dr. Ward's representation does not indicate ASE endorsement of this guideline.

^rOfficial Society of Thoracic Radiology Representative.

¹Ottawa Hospital Research Institute and Medical Imaging, The Ottawa Hospital.

²Department of Radiology, The University of Ottawa.

Corresponding author and reprints: Frank J. Rybicki, MD, PhD, The Ottawa Hospital, Medical Imaging, 501 Smyth Road, Ottawa, ON, Canada K1H 8L6; e-mail: frjbicki@toh.on.ca

TABLE OF CONTENTS

INTRODUCTION	e4
RATING GUIDE	e4
Methods for Establishing Appropriate Use of Imaging in ED Patients With CP	e4
Clinical Scenario and Indication Identification by Writing Group	e4
Definition of Appropriateness	e4
DEFINITIONS	e5
Non–ST-Segment Elevation ACS	e5
AAS	e5
CP Related to ACS	e5
ABBREVIATIONS (SEE APPENDIX 1)	e5
ASSUMPTIONS	e5
General Clinical Assumptions	e5
Practice Parameters/Standard of Care	e5
Cost/Value	e5
Guidance Specifically for Appropriate Use Criteria Users	e5
Entry Criteria Into Algorithms	e5
Testing Considerations	e7
Comorbidities and Contraindications	e8
Availability and Expertise	e8
Assessing the Risk for ACS in Patients With Suspected ACS	e8
SECTION 1: IMAGING OF PATIENTS FOR WHOM THE INITIAL WORKUP IS DIAGNOSTIC FOR STEMI OR FOR WHOM A NONCARDIAC DIAGNOSIS IS LIKELY	e9
Clinical and Imaging Rationale	e9
Description of Clinical Scenarios	e9
Clinical Scenario 1: Diagnostic Electrocardiogram for STEMI	e9
Clinical Scenario 2: Initial History or Physical Examination and/or Chest Radiography Identifies a Likely Noncardiac Diagnosis	e9
SECTION 2: IMAGING OF PATIENTS WITH CP AND A LEADING DIAGNOSIS OF NON–ST-SEGMENT ELEVATION ACS	e9
Clinical Rationale	e9
Early Assessment Pathway and Observational Pathway	e10
Description of Clinical Scenarios in the Early Assessment Pathway	e12
Clinical Scenario 3: Initial ECG and/or Biomarker Analysis Unequivocally Positive for Ischemia	e12
Clinical Scenario 4: Equivocal Initial Troponin or Single Troponin Elevation Without Additional Evidence of ACS	e12
Clinical Scenario 5: Ischemic Symptoms Resolved Hours Before Testing	e12
Clinical Scenario 6: TIMI Risk Score = 0, Early hsTrop Negative	e12
Clinical Scenario 7: Normal or Nonischemic Initial ECG, Normal Initial Troponin	e12
Description of Imaging Modalities	e12
Resting SPECT Myocardial Perfusion Imaging	e12
Echocardiography	e13
CCTA	e13
CMR	e14
CCath	e14
Description of Clinical Scenarios in the Observational Pathway	e14
Clinical Scenario 8: Any Electrocardiogram and/or Serial Troponins Unequivocally Positive for NSTEMI or ACS	e14
Clinical Scenario 9: Serial ECG and Troponins Negative for NSTEMI or ACS	e15

This document was approved by the American College of Radiology Board of Chancellors and the American College of Cardiology Board of Trustees in June 2015.

The American College of Radiology requests that this document be cited as follows: Rybicki FJ, Udelson JE, Peacock WF, Goldhaber SZ, Isselbacher EM, Kazerooni E, Kontos MC, Litt H, Woodard PK. 2015 ACR/ACC/AHA/AATS/ACEP/ASNC/NASCI/SAEM/SCCT/SCMR/SCPC/SNMMI/STR/STS appropriate utilization of cardiovascular imaging in emergency department patients with chest pain: a joint report of the American College of Radiology Appropriateness Criteria Committee and the American College of Cardiology Appropriate Use Criteria Task Force. *J Am Coll Radiol* 2015;12:XXX

Copies: This document is available on the World Wide Web sites of the American College of Cardiology (<http://www.acc.org>) and the American College of Radiology (<http://www.acr.org>). For copies of this document, please contact Elsevier Inc Reprints Department via fax, (212) 633-3820, or e-mail, reprints@elsevier.com.

Permissions: Multiple copies, modification, alteration, enhancement, and/or distribution of this document is not permitted without the express permission of the American College of Cardiology. Requests may be completed online via the Elsevier site (<http://www.elsevier.com/authors/obtaining-permission-to-re-use-elsevier-material>).

Clinical Scenario 10: Serial ECG or Troponins Borderline for NSTEMI or ACS	e15	Clinical Scenario 16: Hemodynamically Unstable Patient, Regardless of Prior Aortic Intervention	e19
Description of Diagnostic Studies	e15	Clinical Scenario 17: Hemodynamically Stable Patient, No Prior Aorta Intervention ..	e19
Exercise ECG Without Imaging	e15	Clinical Scenario 18: Hemodynamically Stable Patient, Prior Aorta Intervention ..	e19
Stress Echocardiography	e15	Description of Imaging Modalities	e20
Stress SPECT and PET	e16	CTAo	e20
Stress CMR	e16	MRAo	e20
SECTION 3: IMAGING OF PATIENTS WITH SUSPECTED PE	e16	Transthoracic Echocardiography	e20
Clinical Rationale	e16	TEE	e20
Imaging Rationale	e16	AoCath	e20
Description of Clinical Scenarios	e17	SECTION 5: IMAGING OF PATIENTS FOR WHOM A LEADING DIAGNOSIS IS PROBLEMATIC OR NOT POSSIBLE	e20
Clinical Scenario 11: D-Dimer Negative and Not High Likelihood by a Clinical Scoring Algorithm	e17	Clinical Rationale	e20
Clinical Scenario 12: D-Dimer Positive and Not High Likelihood by a Clinical Scoring Algorithm	e17	Imaging Rationale and Description of Imaging	e20
Clinical Scenario 13: High Likelihood by a Clinical Scoring Algorithm	e17	Description of Scenarios	e21
Description of Imaging Modalities	e17	Clinical Scenario 19: Overall Likelihood of ACS, PE, or AAS Is Low	e21
CTPA	e17	Clinical Scenario 20: Overall Likelihood of ACS, PE, or AAS Is Not Low	e21
Pulmonary Scintigraphy/VQ	e18	PRESIDENT AND STAFF	e21
Pulmonary MR Angiography	e18	ACR Board of Chancellors Chair and Staff ..	e21
PCath	e18	American College of Cardiology President and Staff	e21
CompUS	e18	APPENDIX 1: Abbreviations	e21
SUSPECTED PE IN PREGNANCY	e18	APPENDIX 2: ACR/ACC/AHA/AATS/ACEP/ ASNC/NASCI/SAEM/SCCT/SCMR/ SCPC/SNMMI/STR/STS 2015 Appropriate Utilization Of Cardiovascular Imaging in Emergency Department Patients With CP Writing Group, Rating Panel, Task Force, and Indication Reviewers—Relationships With Industry and Other Entities (Relevant)	e22
Imaging Rationale	e18	REFERENCES	e24
Description of Clinical Scenarios	e18		
Clinical Scenario 14: Pregnant Patient With Leg Symptoms	e18		
Clinical Scenario 15: Pregnant Patient With No Leg Symptoms	e18		
SECTION 4: IMAGING OF PATIENTS WITH SUSPECTED ACUTE SYNDROMES OF THE AORTA	e18		
Clinical Rationale	e18		
Imaging Rationale	e19		
Description of Clinical Scenarios	e19		

INTRODUCTION

The 2010 National Hospital Medical Care Survey reported nearly 130 million emergency department (ED) visits [1]. The second largest component, 5.4%, were patients presenting with chest pain (CP) [1]. In the patient presenting with undifferentiated CP, the spectrum of potential etiologies ranges from serious, immediate, life-threatening pathologies such as acute coronary syndromes (ACS), pulmonary embolism (PE), or acute aortic syndromes (AAS) to relatively benign illness without long-term consequences (such as costochondritis) and poses a great challenge to the caregiving physician. The initial strategy focuses on rapidly and accurately excluding diagnoses with the greatest short-term mortality risk. Much of the initial diagnosis is determined by the clinical presentation as assessed by the history, physical examination, and basic ancillary testing. However, diagnostic imaging may be used to identify or exclude a potential life-threatening condition when the clinical presentation does not reveal an obvious cause.

RATING GUIDE

Methods for Establishing Appropriate Use of Imaging in ED Patients With CP

Clinicians, payers, and patients are interested in the incremental value offered by imaging to both the diagnosis and clinical management of disease conditions and, alternatively, when imaging does not offer this value. This document addresses the appropriate use of imaging in patients who present to an ED with CP. Imaging appropriateness explicitly considers two questions: (1) Is any imaging justified for 20 clinical scenarios that categorize patients after history, physical examination, and ancillary testing? and (2) If justified, what meaningful incremental information will an imaging procedure provide? This document combines evidence-based medicine, guidelines, and practice experience by engaging a rating panel in a modified Delphi exercise [2]. This document follows the methods as described in a joint publication by the American College of Cardiology and the ACR [3]. When more than one imaging study is considered appropriate for a clinical scenario, the methods do not consider preferred individual modalities among all of those rated appropriate. Clinicians should include all factors including costs as well as local availability and expertise when ordering imaging studies.

Clinical Scenario and Indication Identification by Writing Group

The Emergency Department Patients With Chest Pain Writing Panel comprised practicing emergency medicine, cardiology, and radiology representatives from the

relevant professional societies. The writing panel recognized key diagnoses related to patients who present to the ED with CP for which imaging may be relevant to diagnosis and management. Because the charge of the writing group is to describe common clinical scenarios seen in contemporary practice, the document is organized with respect to diagnostic algorithms from four key clinical entry points that direct imaging (see Fig. 1):

1. Suspected non—ST-segment elevation ACS (clinical scenarios 1-10)
2. Suspected PE (clinical scenarios 11-15)
3. Suspected acute syndrome of the aorta (clinical scenarios 16-18)
4. Patients for whom a leading diagnosis is problematic or not possible (clinical scenarios 19 and 20)

Definition of Appropriateness

The ACR and American College of Cardiology definition of an “appropriate” imaging test is as follows [4]:

The concept of appropriateness, as applied to health care, balances risk and benefit of a treatment, test, or procedure in the context of available resources for an individual patient with specific characteristics. Appropriateness criteria provide guidance to supplement the clinician’s judgment as to whether a patient is a reasonable candidate for the given treatment, test or procedure.

This definition highlights the central pursuit of the greatest yield of clinically valuable diagnostic information from imaging with the least negative impact on the patient.

On the basis of available evidence, the Emergency Department Patients With Chest Pain Rating Panel members assigned a rating to each imaging procedure for each of the 20 clinical scenarios on a scale ranging from 1 to 9 as follows:

Appropriate rating 7, 8, or 9: An appropriate option for the management of patients in this population because of benefits generally outweighing risks; an effective option for individual care plans although not always necessary depending on physician judgment and patient specific preferences (ie, the procedure is generally acceptable and is generally reasonable for the indication).

May be appropriate rating 4, 5, or 6: At times an appropriate option for the management of patients in this population because of variable evidence or agreement regarding the benefit/risk ratio, potential benefit on the basis of practice experience in the absence of evidence, and/or variability in the population; effectiveness for individual care must be determined by a patient’s physician in consultation with the patient on the basis of additional clinical variables and judgment

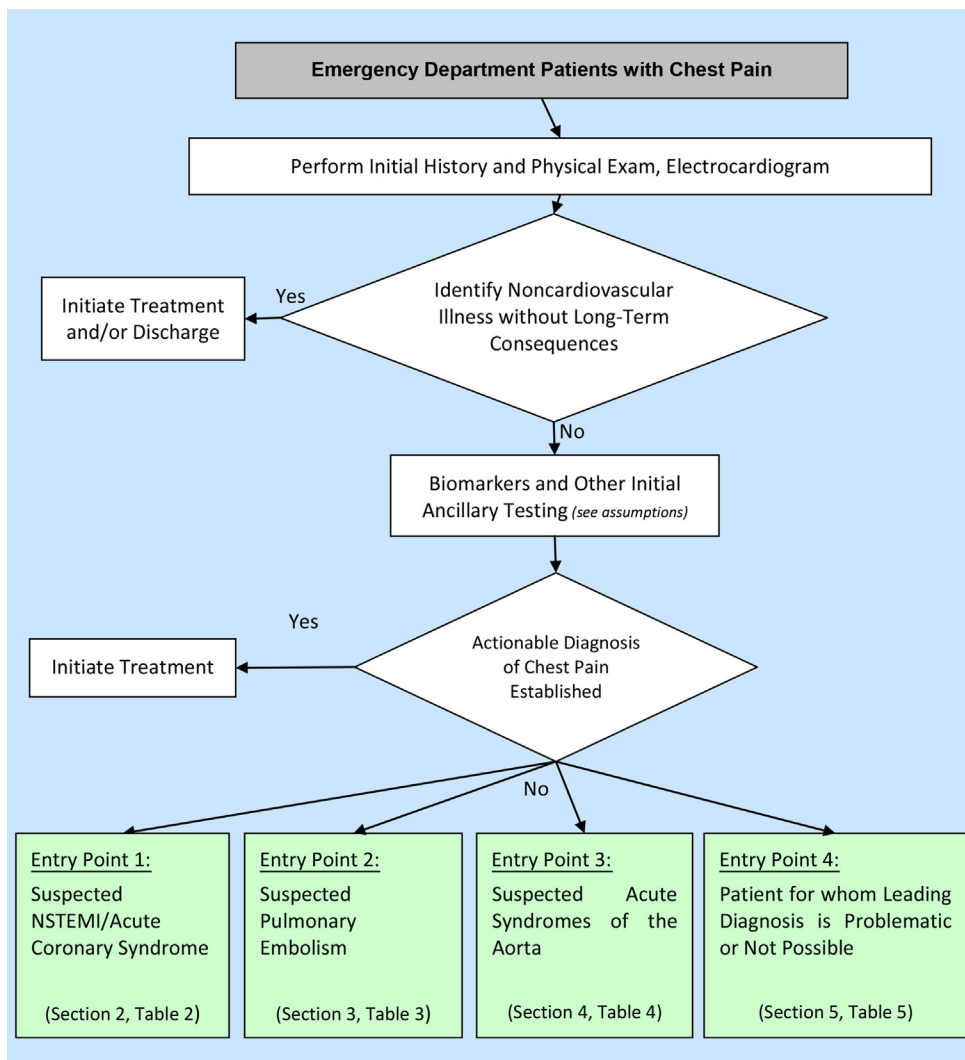


Figure 1. Entry points for clinical scenarios under consideration.

along with patient preferences (ie, the procedure may be acceptable and may be reasonable for the indication).

Rarely appropriate rating 1, 2, or 3: Rarely an appropriate option for the management of patients in this population because of the lack of a clear benefit/risk advantage; rarely an effective option for individual care plans; exceptions should have documentation of the clinical reasons for proceeding with this care option (ie, the procedure is not generally acceptable and is not generally reasonable for the indication).

Consensus was reached when 60% or greater of the panel members assigned a rating within one of the three categories: appropriate (A), may be appropriate (M), or rarely appropriate (R). When consensus was not reached for a study within a particular clinical scenario, regardless of the rating panel scores, the rating was assigned M*, or may be appropriate*,

with the asterisk referring to the fact that the rating of M* was from absence of consensus as opposed to M, indicating that consensus was reached in the may be appropriate category.

DEFINITIONS

Non–ST-Segment Elevation ACS

Any group of clinical symptoms compatible with acute myocardial ischemia, including unstable angina and non–ST-segment elevation myocardial infarction (NSTEMI).

AAS

Any group of clinical symptoms compatible with aortic dissection, intramural hematoma, and symptomatic aortic ulceration.

CP Related to ACS

Any constellation of anginal or anginal-equivalent symptoms that the physician feels may represent a condition resulting from obstructive coronary artery disease (CAD). Examples of such symptoms include but are not exclusive to CP, chest tightness, burning, shoulder pain, and jaw pain or “angina equivalents” such as dyspnea.

ABBREVIATIONS (SEE APPENDIX 1)

ASSUMPTIONS

General Clinical Assumptions

To limit inconsistencies in interpretation, specific assumptions were considered by the writing group in development and were used by the rating panel. Assumptions associated with specific presentations are also reviewed in the following respective sections.

Practice Parameters/Standard of Care

All imaging is performed by qualified personnel in an accredited laboratory using standardized imaging protocols.

Clinicians should consider ionizing radiation when choosing an imaging modality for a patient in a specific clinical scenario. Radiation exposure should be minimized in all patients according to the principle of “as low as reasonably achievable.” Tests involving radiation should use protocols [5] that deliver the least possible radiation dose but preserve image quality and sensitivity [6].

Cost/Value

From the standpoint of the practicing emergency medicine physician caring for an individual patient, the potential clinical benefits of an appropriate imaging study should be the highest priority, and these are weighed against potential risks of performing either no imaging study or an alternative study.

As related to societal benefits, costs should also be considered in relation to potential benefits in order to better understand comparative value. However, there is a relative paucity of data to assess cost-effectiveness among multiple studies. When available, these data are noted by the writing panel, and cost/value data are considered, if deemed appropriate, by rating panel members.

Guidance Specifically for Appropriate Use Criteria Users

Reducing imaging that is “rarely appropriate” is considered a potentially valuable means to reduce costs and population

risks in cardiovascular imaging among patients who present to emergency medicine physicians with CP.

The category “may be appropriate” should be used when insufficient clinical data are available for a definitive categorization or there are substantial differences in opinion regarding the appropriateness of that indication. The absence of definitive data supporting a specific imaging study for a particular subset of patients does not imply a lack of benefit, and in such cases, careful investigation of the particulars of the clinical scenario is warranted. The designation “may be appropriate” should not be used as the sole grounds for denial of reimbursement for a given examination for a specific clinical scenario.

Entry Criteria Into Algorithms

1. All adult patients presenting to EDs with potential CP syndromes will undergo evaluations that generally include history and physical examination, immediate electrocardiography (ECG) to identify or exclude ST-segment elevation myocardial infarction (STEMI), and cardiac and/or pulmonary biomarker analysis (troponin and/or D-dimer) (Fig. 1). Some patients will be diagnosed with noncardiovascular illnesses that exclude ACS, PE, and AAS, and in general, no imaging is required. Patients with evidence of STEMI on initial ECG or initial biomarkers and/or ECG clearly consistent with ACS or NSTEMI are admitted and treated according to evidence-based guidelines. These patients are, in general, not the subjects of this document.
2. Table 1 evaluates the role of imaging in the process of the initial workup, with two common scenarios that include patients for whom ECG is diagnostic for STEMI and patients for whom an alternative, noncardiac diagnosis is likely.
3. After the initial evaluation, it is assumed that the physician will be able to clinically risk-stratify the majority of those remaining patients into one of the three suspected diagnoses of concern: ACS (section 2), PE (section 3), and AAS (section 4). Section 5 includes the minority of patients for whom a leading diagnosis is not possible. Sections 2 through 5 assume that the initial workup and ancillary testing, including cardiac and/or pulmonary biomarkers, are completed (Fig. 1).
4. Some patients who enter the clinical scenarios and undergo imaging studies will have inconclusive data to confirm or exclude a leading diagnosis after imaging. Although ratings for sections 2 through 5 may have more than one imaging study that may be considered appropriate, this document does not specifically

Table 1. Imaging of Patients for Whom the Initial Workup Is Diagnostic for STEMI or for Whom a Noncardiac Diagnosis Is Likely

Indication	Chest Radiography	Echocardiography Rest	CMR Rest	SPECT Rest	CCTA	CCath
1. Diagnostic ECG for STEMI	M	R	R	R	R	A
2. Initial history/physical examination and/or chest radiography identifies a likely noncardiac diagnosis (eg, pneumothorax, costochondritis, lesion in the esophagus)		R	R	R	R	R

Appropriate use key: A = appropriate; M = may be appropriate with rating panel consensus; R = rarely appropriate. CCath = catheter-based coronary angiography; CCTA = coronary CT angiography; CMR = cardiovascular MR; ECG = electrocardiogram; SPECT = single-photon emission computed tomography; STEMI = ST-segment elevation myocardial infarction.

address the appropriate use of a second imaging study. The writing group acknowledges that although such patients can present a diagnostic dilemma, there are limited or no data on which to establish appropriate use criteria for the second study, particularly because findings from the first study may influence the best choice for subsequent imaging.

- One-third of patients with confirmed acute myocardial infarction (AMI) will not have typical CP; section 2 includes those patients.
- Imaging in the ED alone, or during evaluation in an observation unit, is considered in this document. Some patients may be candidates for outpatient referrals for follow-up imaging in lower intensity settings. The clinical scenarios in this document in general do not cover these referrals, nor does this document include imaging for patients who do not present to the ED.
- Miniaturization of ultrasound technology has enabled the use of focused cardiac ultrasound (FOCUS), or bedside ultrasonography performed by the emergency medicine physician, using highly portable equipment that lends itself well to use in an ED setting when a rapid evaluation is required. The writing panel gave specific consideration to FOCUS as an expedited method for bedside diagnoses [7]. FOCUS is recognized as a universal part of emergency medicine training and practice. It is valuable in selected patients considered in this document, in particular those who present with CP or shortness of breath. Although it can assess left and right ventricular dysfunction, determine volume status, evaluate the fluid status of the lungs, and exclude some items in the initial differential diagnosis, its main utility for patients covered by the current guidelines is to detect pericardial fluid in patients with suspected cardiac tamponade [8].

With respect to ACS, although FOCUS can accurately estimate ejection fraction with good interrater reliability, FOCUS alone is not useful in ruling in or out an ACS. Echocardiographers have found that the absence of regional wall motion abnormalities has a negative predictive value (NPV) of 82% to 98% for AMI [9-12]. One study reported that sensitivity among patients with NSTEMI was only 86% [10]. Thus, like echocardiography, FOCUS is not considered sufficient to allow safe discharge from the ED. Similarly, FOCUS should not be used alone as the basis for decisions about the disposition of patients with possible ischemic CP. With respect to acute PE, a right ventricle larger in size than the left ventricle and paradoxical septal motion can suggest PE, but this observation on FOCUS should not preclude additional imaging. With respect to acute syndromes of the aorta, other than detecting tamponade, FOCUS is unlikely to provide diagnostic help in patients with suspected aortic dissection.

Although appropriate for patients who present to emergency medicine physicians with CP, FOCUS was not considered by the rating panel because it is inherently the initial examination performed by emergency medicine physicians, and subsequent imaging as noted in this document is also appropriate. FOCUS is indicated for the proper, rapid identification and exclusion of key cardiovascular diagnoses as indicated by existing guidelines [7].

Testing Considerations

- This report considers exercise treadmill testing without imaging and stress testing with imaging, including the following: echocardiography, cardiovascular MR (CMR), and nuclear imaging, including single-photon emission computed tomography (SPECT). This report considers CT for the coronary arteries (coronary CT

angiography [CCTA]), for the pulmonary arteries (CT pulmonary angiography [CTPA]), and for the aorta (CT aortography [CTAo]). The report also considers CT scans tailored to identify all three diagnoses, or “triple-rule-out” (TRO) CT. This report considers invasive diagnostic catheterization that can be tailored to evaluate patients with clinically suspected ACS (CCath), PE (PCath), or AAS (catheter-based aortography [AoCath]). Although invasive catheterization can be coupled with an intervention, for the purposes of this document, *catheterization* refers only to the diagnostic portion of an overall procedure.

- Although ratings for TRO studies (Table 5) include specific scenarios, it is acknowledged that more generally, no single test provides optimal performance for all three diagnoses (ACS, PE, and AAS).
- All tests considered in this document have multiple capabilities, both as stand-alone technologies and for use in combination during the evaluation of individual patients. This document is not intended to describe imaging technologies; descriptions are intended to reflect the capabilities of modern imaging for emergency medicine patients.
- The quality of the imaging data in clinical use will be reflective of the quality of the imaging data demonstrated in representative clinical trials. The quality of imaging data is a result of many steps, including data acquisition, processing, interpretation, and reporting.
- Improvements in the analytic performance of cardiac troponin (cTn) assays have resulted in improved

sensitivity and precision, resulting in the ability to measure 10-fold lower concentrations of cTn with high precision. These “high-sensitivity” cTn assays, defined as those that can measure cTn in at least 50% of healthy individuals, are not currently available in the United States, although they are already in clinical use throughout most of the world [13]. The increased sensitivity of newer cTn assays allows potentially more rapid diagnosis of patients with myocardial infarction (MI), particularly early after symptom onset, compared with contemporary assays currently in wide use. However, the higher sensitivity may lead to the detection of cTn in a substantial proportion of patients who do not have ACS but have other underlying cardiovascular diseases, such as heart failure [14]. Given the absence of widespread availability in the United States at the time of development of this document, recommendations contained herein regarding the use of troponins in the evaluation pathway of patients will generally reflect data from currently available assays [13,14]. However, as literature on the use of this type of testing is emerging, this document includes one clinical scenario that incorporates high-sensitivity troponin testing, scenario 6 in Table 2.1. Several studies have shown that patients with Thrombolysis in Myocardial Infarction (TIMI) risk scores of 0 and negative results for high-sensitivity troponin at presentation or presentation after 2 hours are at very low risk for ACS [15].

Table 2.1. Suspected Non–ST-Segment Elevation ACS: Early Assessment Pathway Based on Initial ECG, Biomarker Analysis, and Symptoms

Indication	Echocardiography	CMR	SPECT	CCTA	CCath
	Rest	Rest	Rest		
Positive initial diagnosis of NSTEMI/ACS					
3. Initial ECG and/or biomarker analysis unequivocally positive for ischemia	R	R	R	R	A
Equivocal initial diagnosis of NSTEMI/ACS					
4. Equivocal initial troponin or single troponin elevation without additional evidence of ACS	M*	M*	A	A	R
5. Ischemic symptoms resolved hours before testing	R	M	M*	A	R
Low/intermediate likelihood initial diagnosis of NSTEMI/ACS					
6. TIMI risk score = 0, early hsTrop negative	R	R	R	A	R
7. Normal or nonischemic on initial ECG, normal initial troponin	R	R	M*	A	R

Appropriate use key: A = appropriate; M = may be appropriate with rating panel consensus; M* = may be appropriate as determined by lack of consensus by rating panel; R = rarely appropriate.

ACS = acute coronary syndrome; CCath = catheter-based coronary angiography; CCTA = coronary CT angiography; CMR = cardiovascular MR; ECG = electrocardiography; hsTrop = high-sensitivity troponin T; NSTEMI = non–ST-segment elevation myocardial infarction; SPECT = single-photon emission computed tomography; TIMI = Thrombolysis in Myocardial Infarction.

Comorbidities and Contraindications

Patients under consideration for rating among imaging tests do not have specific comorbidities or contraindications as noted below.

1. Unless otherwise stated, the following absolute or relative contraindications that would preclude certain types of imaging are assumed not to be present: claustrophobia, pregnancy, iodine allergy, renal dysfunction, and high resting heart rate.
2. Imaging studies that deliver ionizing radiation are, in general, relatively contraindicated during pregnancy.
3. Gadolinium-enhanced MRI is, in general, not performed in patients who are pregnant.

Availability and Expertise

1. Geographic or regional variability: issues of local availability and of skill in conducting each potential imaging study are not considered by the rating panel. Specifically, it is assumed that credentialed laboratories staffed by skilled imagers are locally available.
2. Radiotracers for nuclear imaging studies and interpreting personnel may not be available at all hours for testing, although some centers with significant off-hours volume have set up mechanisms for 24/7 testing.
3. Although the technology and expertise are generally available on an institutional basis, a qualified technologist (eg, a sonographer) may not be readily available to an ED, and it may be less likely that a reader is immediately available for studies performed after hours.
4. CCTA using 64-channel or greater cardiac CT systems [16] is now available for many emergency medicine services. Although CT scanners and expertise are generally available on an institutional basis and often include 24/7 service to the ED for CTPA and CTAo, specific capabilities for CCTA may not be readily available to the ED, especially for studies performed after hours.

Assessing the Risk for ACS in Patients With Suspected ACS

In many studies cited in this document and throughout section 2, reference is made to “low”, “intermediate,” or “high” risk. Although the term *risk* is used, the term refers to the likelihood that an ACS is present given a certain set of clinical findings (or alternatively risk for short-term ACS “events”) [17]. For patients with suspected ACS, determination of likelihood of disease on the basis of any of the traditional methods such as those recommended by the American Heart Association scientific statement can help direct further testing and imaging in this group.

From the literature, there are no widely agreed-upon, post hoc, numerical thresholds that distinguish these categories, as there are for categories of risk for coronary heart disease using the Framingham risk score, for instance. The Rule-Out Myocardial Infarction/Ischemia Using Computer Assisted Tomography trials aimed to enroll patients with suspected ACS at “low to intermediate” risk [18,19]. The prevalence of a final diagnosis of ACS among the enrolled population was approximately 8%, and this was considered an intermediate-risk population. In a study of 2,271 patients presenting with CP to EDs, initial clinical criteria were able to identify what was termed a low-risk group, with a 30-day major cardiovascular event rate (death, MI, stroke, or revascularization) of 2.5% [20].

Clinical risk assessment involves evaluation of symptoms, initial ECG, and initial biomarkers [21]. Several scoring systems have been developed and validated in this population to various degrees, including the Agency for Health Care Policy and Research (now the Agency for Healthcare Research and Quality) CP score [20] and the TIMI score [22,23]. For the purpose of this document, reference is made to specific scoring systems in clinical scenarios on the basis of published literature that would inform ratings of imaging tests. Regarding these scoring tools, it is important to note that initial validation often occurs in a population of patients from clinical trials for which the diagnosis of ACS is definitive. Whether these tools all translate into the lower risk population of ED patients with suspected ACS is not always as yet well validated [22].

SECTION 1: IMAGING OF PATIENTS FOR WHOM THE INITIAL WORKUP IS DIAGNOSTIC FOR STEMI OR FOR WHOM A NONCARDIAC DIAGNOSIS IS LIKELY

Clinical and Imaging Rationale

Much of the initial triaging of patients presenting with CP comes from defining the clinical presentation as assessed by the history and physical examination and initial ECG. Patients not easily placed into one of these scenarios from additional information and/or risks are considered in subsequent sections and tables.

Description of Clinical Scenarios

Clinical Scenario 1: Diagnostic Electrocardiogram for STEMI. In patients for whom ECG shows STEMI, CCath has been shown to be beneficial when delivered rapidly [24]. Portable chest radiography has been studied for limited use in this setting of suspected ACS [21], on the basis of the individual patient care environment, and

found to be of low yield. Although no study should delay the “door-to-balloon” time, unless a potential contraindication, such as aortic dissection, is suspected [25], portable chest radiography may be appropriate because it can exclude a secondary pathology (eg, pneumonia, pneumothorax, abnormal line placement) important to communicate with the catheterization staff.

Clinical Scenario 2: Initial History or Physical Examination and/or Chest Radiography Identifies a Likely Noncardiac Diagnosis. Diagnoses with high short-term mortality risk, such as ACS, PE, and AAS, may be ruled out at this stage on the basis of patient history, physician examination, and chest radiography. In this scenario, all imaging modalities under consideration are considered rarely appropriate.

SECTION 2: IMAGING OF PATIENTS WITH CP AND A LEADING DIAGNOSIS OF NON—ST-SEGMENT ELEVATION ACS

Clinical Rationale

CP and other conditions consistent with possible myocardial ischemia (or rule-out ACS) are among the most common ED presentations. CP represents a high-volume, potentially high-risk scenario in which the majority of patients are actually at low risk for ACS. Over the past 20 years, there has been substantial progress on improving methods that can accurately and rapidly identify the relatively few high-risk ACS patients among the large presenting volume of low-risk patients.

Obtaining a history is of critical importance in the initial evaluation of ED CP patients. Although often not sufficient to exclude myocardial ischemia in a particular patient, a history allows risk stratification into high-, intermediate-, and low-risk groups in which additional diagnostic testing, such as cardiac marker analysis and imaging techniques, can be more appropriately targeted. The characteristics of the pain and the presence of associated symptoms are useful for risk stratification [17,20]. Although risk factors for coronary disease are often assessed, they have limited value for identifying patients with MI because they are frequently outweighed by the CP characteristics, history of coronary disease, and findings on ECG [26].

A number of risk stratification models that combine clinical and electrocardiographic findings have been shown to predict short-term outcomes in patients with symptoms suggestive of myocardial ischemia [17,20,21]. These algorithms have similar sensitivity but significantly higher specificity than physicians' evaluations, potentially identifying lower risk patients who could be evaluated in lower

intensity settings or discharged home. Despite these potential advantages, few algorithms have been incorporated into standard practice. One risk stratification algorithm is the TIMI risk score, which is composed of seven variables of equal weight. Although the TIMI score was initially derived and validated in a clinical trial population with definite ACS, subsequent studies in lower risk ED patients have also shown that it can assist in risk stratification, although to a lesser degree [27]. Recent studies have suggested that when contemporary troponin testing at 0 and 2 hours is combined with a TIMI risk score of 0 (adapted to include only the initial troponin value), occurring in approximately 10% of all ED CP patients, such a strategy may identify patients at very low risk [28,29].

ECG is the initial test in patients with CP or suspected ACS because it can be performed rapidly, is inexpensive, and can readily identify STEMI patients who will benefit from early reperfusion. The presence of ischemic changes, including ST-segment depression [21], identifies a high-risk patient group, while conversely, completely normal findings on ECG identify a group of patients at relatively lower risk for MI and ischemic complications, the majority of whom can be evaluated in lower intensity settings, such as observation units. The presence of normal electrocardiographic findings on initial presentation in those patients eventually ruling in for MI identifies a group at lower risk for mortality and unfavorable outcomes compared with those with ischemic changes, but the absolute event rates are not low enough to drive discharge triage decisions [17,30].

In all patients with suspected ACS, the early determination of biomarker (troponin) status is very important because many diagnostic and treatment decisions will be, in part, determined by troponin positivity or negativity. Although the previous description of the acquisition of information implies serial determination of history, physical examination, chest radiography, and biomarker analysis, in practice, many of these are done in parallel.

The presence of clear ischemic changes on initial ECG, either ST-segment elevation or depression, identifies an ACS patient in whom admission and rapid management are mandatory; in this case, the initial triage and treatment strategy is guideline driven [24]. However, diagnostic initial electrocardiographic findings are present in only a minority of patients. The remaining clinically stable patients have possible myocardial ischemia and suspected NSTEMI ACS. It is this group in which subsequent risk stratification evaluation and potential use of additional diagnostic tools such as imaging modalities are needed.

Because of the limitations of historical, physical examination, and electrocardiographic data, many of these patients are admitted or placed into observation units, though most are later determined to have nonischemic causes of their symptoms. Despite this low threshold for admission, some patients with AMI are inadvertently discharged [31], with subsequent morbidity and mortality 2 to 3 times that of those AMI patients who are admitted, on the basis of older studies [32]. Although some of these inadvertently discharged patients may have infarctions, it is likely that some have unstable angina that may subsequently evolve into MI, underscoring the importance of identifying these patients. The findings that 2% of patients with AMI are inadvertently discharged from EDs are based on studies that used less sensitive troponin assays. In current practice, with more sensitive troponin assays, this number is likely to be smaller. In addition, patients with unstable angina who were troponin negative with old assays might be identified by elevated troponin using contemporary assays.

Thus, if the history, initial electrocardiographic results, and troponin biomarkers with or without the use of risk scores are diagnostic for ACS, a triage decision to admit and treat should be made and an evidence-based treatment strategy initiated [21]. If the initial data are sufficient to confirm a diagnosis that is not ACS (such as pericarditis, a diagnosis not considered in this document), direct early discharge from the ED with appropriate follow-up may be warranted. However, after this initial information, uncertainty often continues to exist regarding an ACS diagnosis. It is in this population—patients with suspected NSTEMI or ACS—that further workup and risk stratification are warranted. In this document, we consider two pathways of further workup: an early assessment pathway and an observational pathway.

Early Assessment Pathway and Observational Pathway

For the purpose of this document, to frame the appropriate use of cardiovascular imaging techniques within the clinical context of their use in this setting, we adopt two pathways for the evaluation of ED patients with suspected ACS. The first evaluation pathway is referred to as the early assessment pathway. With this strategy, imaging may be used early in the evaluation process, with the goal of ruling in or ruling out ACS or MI through the identification of wall motion abnormalities, perfusion defects, or obstructive CAD without the need to wait for serial biomarker analysis. Imaging tests in this pathway do not require stress physiology but rather image anatomy

(CCTA), function (echocardiography, CMR), or perfusion (resting SPECT, CMR) at rest. Stress examinations were not considered by the rating panel in the early assessment pathway. Patients in the ED with CP syndromes and history of MI or revascularization (ie, known CAD) may have evidence of resting wall motion or resting perfusion abnormalities, as well as abnormal coronary anatomy by definition, which would confound the evaluation of a new symptom complex suspicious for ACS by these testing modalities. Clinical scenarios 3 to 7 considered in the early assessment pathway appear in [Table 2.1](#).

The second pathway is referred to as the observational pathway, and it involves serial analysis of cardiac biomarkers to rule in or out myocardial necrosis and MI. Testing in this pathway may involve stress physiologic testing, and thus stress examinations were considered by the rating panel in clinical scenarios 8 to 10. Assessments at rest are generally less appropriate for patients managed in the observational pathway. Patients in the ED with CP syndromes and history of MI or revascularization (ie, known CAD) may have evidence of resting and/or stress wall motion or perfusion abnormalities, as well as abnormal coronary anatomy, which, as noted previously, would complicate the evaluation of a new symptom complex suspicious for ACS, although stress testing would identify currently existing ischemia. Ratings for the observational pathway appear in [Table 2.2](#).

Description of Clinical Scenarios in the Early Assessment Pathway

The early assessment pathway uses tests to inform the ED physician regarding ACS for purposes of triage decision making. Some tests provide information that may be generally useful for management purposes (eg, assessment of ejection fraction), but these are not directly useful for the diagnostic purpose of identifying a patient with an ACS. Patients considered in this pathway may or may not have ongoing symptoms. Some physiologic testing, such as analysis of wall motion abnormalities, is, importantly, influenced by whether ischemia is ongoing, whereas other modalities, such as coronary CT angiographic assessment of coronary anatomy, are not. Studies have suggested that perfusion imaging test results may remain positive for a resting perfusion abnormality several hours after symptom resolution [33].

Clinical Scenario 3: Initial ECG and/or Biomarker Analysis Unequivocally Positive for Ischemia. CCath is beneficial in patients in whom initial ECG and/or biomarker analysis is unequivocally positive for ischemia, as revascularization may be associated with more favorable outcomes [21,34-36]. Thus, CCath is considered

Table 2.2. Suspected Non–ST-Segment Elevation ACS: Observational Pathway—After Assessment of Serial Cardiac Troponin

Indication	Exercise ECG	Echocardiography		CMR		SPECT/PET		CCTA	CCath
		Rest	Stress/ Rest	Rest	Stress/ Rest	Rest	Stress/ Rest		
8. Diagnosis unequivocally positive for NSTEMI/ACS	M*	M*	M*	M*	M*	M*	M*	M*	A
Serial troponins or ECG not positive for NSTEMI/ACS									
9. Serial ECG and troponins negative for NSTEMI/ACS	A	R	A	R	A	R	A	A	R
10. Serial ECG or troponins borderline for NSTEMI/ACS	M*	M*	A	R	A	R	A	A	M*

Appropriate use key: A = appropriate; M* = may be appropriate as determined by lack of consensus by rating panel; R = rarely appropriate. ACS = acute coronary syndrome; CCath = catheter-based coronary angiography; CCTA = coronary CT angiography; CMR = cardiovascular MR; ECG = electrocardiography; NSTEMI = non–ST-segment elevation myocardial infarction; SPECT = single-photon emission computed tomography.

appropriate, whereas all other rest imaging modalities are considered rarely appropriate.

Clinical Scenario 4: Equivocal Initial Troponin or Single Troponin Elevation Without Additional Evidence of ACS. In such patients, the diagnosis of ACS remains uncertain. Both rest SPECT and CCTA are appropriate and have been evaluated in randomized trials [19,37,38]. Rest echocardiography and rest CMR may be appropriate, and CCath is rarely appropriate.

Clinical Scenario 5: Ischemic Symptoms Resolved Hours Before Testing. Assessment for wall motion abnormalities by echocardiography or other testing is dependent on the presence of ongoing ischemia. Thus, if symptoms have resolved many hours before assessment, such tests will be insensitive for the diagnosis of ACS. Resting perfusion abnormalities may persist for several hours after ischemia resolves, although it is unknown at what time point sensitivity decreases [33]. Clinical trials using rest perfusion imaging to distinguish ACS versus non-ACS CP and improve triage have allowed enrollment of patients up to 3 hours after symptom resolution [37,39]. In this setting, CCTA is considered appropriate, whereas rest CMR and rest SPECT may be appropriate. Rest echocardiography and CCath are rarely appropriate.

Clinical Scenario 6: TIMI Risk Score = 0, Early hsTrop Negative. As noted under “Testing Considerations,” although high-sensitivity troponins [13] are, at the time of rating, not approved for use in the United States, they are increasingly used outside the United States. Moreover, an emerging body of literature suggests

that incorporating these biomarkers can identify a group of patients already at very low clinical risk whose ACS prevalence and event rate are very low. Conceptually, in such a setting, no further testing may be considered, as the yield would likely be low. The rating panel has considered CCTA appropriate in this setting, as some of the extant trials of CCTA versus standard-of-care evaluation have generally included relatively low-risk populations. In one study, there were no cardiac deaths, and only 1% of patients had MIs within 30 days [38]. In this population, CCTA was rated as appropriate, and all other imaging modalities were rated as rarely appropriate.

Clinical Scenario 7: Normal or Nonischemic Initial ECG, Normal Initial Troponin. This scenario refers to patients in whom the initial electrocardiogram is not diagnostic for ischemic changes and the initial troponin result (not high-sensitivity assay) is also not diagnostic for NSTEMI or ACS. This scenario represents a large proportion of patients seen in this setting, in whom there generally remains uncertainty about the diagnosis after initial ECG and biomarker analysis. Such patients have been considered at low to intermediate risk for ACS. CCTA is appropriate, and rest SPECT may be appropriate, with data based on randomized trials [19,37,38]. Rest echocardiography, rest CMR, and CCath are rarely appropriate.

Description of Imaging Modalities

Resting SPECT Myocardial Perfusion Imaging. A number of studies have examined the use of resting myocardial perfusion imaging in the setting of suspected

ACS [37,39-43]. Several reports have concluded that the use of resting SPECT in the ED in such patients is associated with shorter length of stay and lower costs and can reduce unnecessary hospital admissions [37,39,43,44]. A large body of observational literature established a high NPV for a normal resting perfusion image to rule out an MI or short-term cardiac events [45]. Two randomized trials have been reported. In a smaller trial, in which management after imaging was protocol directed, a strategy incorporating resting SPECT was associated with shorter length of stay and lower cost, with similar safety [44]. In a much larger trial, in which management after imaging was left to the discretion of the ED physician ("effectiveness," ie, how a test performs in real life to influence decisions), the incorporation of resting SPECT resulted in fewer unnecessary admissions, with an unnecessary admission defined as those patients admitted from the ED whose final diagnoses were not ACS [37]. There was, however, no outcome difference 30 days after ED presentation compared with those who underwent standard ED care. In this latter trial, patients were enrolled if they were within 3 hours of symptom resolution. Resting SPECT is limited in distinguishing chronic from acute ischemia.

Echocardiography. Resting 2-D echocardiography is rapid and noninvasive. Two-dimensional echocardiography provides information about myocardial ischemia by evaluating segmental wall motion and ejection fraction [9,46], but the positive predictive value (PPV) is not high [9,47]. It may detect other possible pathologies that may be associated with CP, such as valvular disease, pericarditis, and cardiomyopathy. Like resting SPECT, 2-D echocardiography is limited in distinguishing chronic from acute ischemia. In addition, resting echocardiography cannot determine the presence of an underlying high-grade coronary stenosis in the absence of impaired myocardial perfusion at rest that results in wall motion abnormalities. Thus, most studies have shown that resting echocardiography to detect acute ischemia is useful only if there are ongoing symptoms at the time of imaging.

When contrast agents are used to assess myocardial perfusion, echocardiography is reported to achieve higher sensitivity than wall motion analysis alone with both rest and stress [48-52]. Although not currently used in routine practice, these methods have moved from research-only tools to clinical availability in some centers of expertise.

CCTA. Coronary calcium scoring was not considered by the rating panel because there are few data on coronary calcium scoring using multidetector CT hardware in patients who present to the ED in whom ACS is the leading differential diagnosis. Moreover, in patients at intermediate to high risk for CAD, a calcium score of 0 is often associated with myocardial ischemia on provocative testing [53]. For patients with coronary calcium detected by CT, the examination would require additional imaging, such as CCTA, that interrogates the coronary lumen.

For patients with CP in the ED, using stenosis detection as a surrogate for ACS and ACS events, CCTA has reported high sensitivity (86%-100%) and NPV (93%-100%), although the PPV using invasive coronary angiography as the reference standard is still limited (50%-90%) [54-58]. CCTA has been used to evaluate not only the severity of stenosis but also plaque characteristics associated with vulnerability and risk for events [18]. However, CCTA is limited in patients with extensive coronary calcium, which generally increases with the risk for ACS as well as with age. Initial reports suggested that a CT-based strategy decreases time to diagnosis (compared with SPECT), length of hospital stay, unnecessary admissions, total costs, and repeat evaluations for recurrent CP, while allowing safe discharge after a negative evaluation [18,56,59,60]. Two large randomized strategy-controlled trials have evaluated the early use of CCTA (ie, before the completion of serial troponin assessments) in patients with low to intermediate likelihood for ACS in the ED setting. Litt et al [38] compared a CCTA pathway with traditional care for safety, defined as absence of MI or cardiac death within 30 days of presentation. Both pathways were found to have a <1% rate of major adverse cardiovascular events (MACEs). Secondary end point analysis demonstrated earlier and more direct ED discharges in the patient group randomized to undergo CCTA as part of their evaluation strategy. Hoffmann et al [19] conducted a randomized controlled trial of 1,000 patients seen at nine US centers, with patients randomized to an early CCTA pathway or standard evaluation. They found as the primary end point that length of stay was shorter among patients randomized to a strategy incorporating early CCTA compared with a standard evaluation strategy. There were no undetected cases of ACS and no significant differences in MACEs. Secondary end points, including time to diagnosis and direct ED discharges, were also favorably affected by CCTA. In a subgroup of patients with full cost information, ED costs were lower in the CCTA strategy group, though overall costs at 30 days were similar.

Radiation exposure was higher in the CCTA group, and there was more downstream testing in the CCTA group. Also, patients in the CCTA arm underwent more revascularization procedures, some of which may have occurred in the absence of a stress test to judge ischemic burden of a lesion. In both of these trials, MACE rates for the CCTA arm and standard of care were less than 1%. The results of the studies of the use of CCTA in the ED have undergone meta-analysis [61] confirming the reduction in length of stay and cost but with slightly increased resulting use of invasive angiography and revascularization downstream.

CMR. Rest CMR can image regional and global ventricular function and myocardial perfusion and identify scar. When it has been used in ED patients, generally in observational studies with modest numbers of patients, contrast-enhanced perfusion, delayed enhancement, and cine evaluation of wall motion have been shown to have sensitivity of 70% to 85% to detect ischemic conditions [62-64]. Normal results on CMR have been associated with a low-risk prognosis. Imaging coronary anatomy has not been done routinely in these studies and is not widely performed; most of the information in the literature involves analysis of perfusion, scar, and function.

CCath. Although catheter angiography remains the clinical standard for the diagnosis of CAD, it has been found to be more limited in value for the initial evaluation of patients at less than high risk for ACS [21]. It can be used to confirm ACS in patients with positive screening results and interventions in the case of perfusion or wall motion abnormalities suggestive of hemodynamically significant stenosis or occlusion or in patients for whom noninvasive testing cannot provide a definitive diagnosis.

Description of Clinical Scenarios in the Observational Pathway

Although the evolution of imaging modalities has enabled the potential use of imaging tests early in the evaluation process, the majority of patients currently seen for assessment of ED CP syndromes—and who do not have initially diagnostic electrocardiographic or biomarker evidence of NSTEMI or ACS—are evaluated in the observational pathway. By definition, patients in this pathway have undergone initial ECG and biomarker testing that has not led to a clear diagnosis of ACS, but ACS is still a consideration. Thus, serial ECG and troponin biomarker analysis are used to rule out NSTEMI or ACS (or rule it in), and if ruled out, stress

testing with or without imaging may be performed to assess for the potential of induction of ischemia. Anatomic testing for CAD with CCTA may also be appropriate in this pathway. The protocol of serial biomarkers followed by more definitive testing in the observational pathway has been evaluated in nonrandomized studies [65] as well as in randomized clinical trials [66,67].

The rating group considered two different groups of patients. The first group comprised patients for whom the diagnosis was unequivocally positive for NSTEMI or ACS from the analysis of serial biomarkers and ECG. The second group of patients comprised those for whom serial troponin and ECG were not positive for NSTEMI or ACS.

By definition of being in the observation pathway and having undergone serial ECG and biomarker assessments, these patients would be at least 9 to 24 hours out from ED presentation. They may still be in the ED, but by the nature of the observational pathway and practices at different hospitals, they also may have been moved to CP evaluation units or telemetry floors.

The intention for this indication was that such patients are clinically stable, having likely received initial guideline-directed medical therapy for possible ACS or NSTEMI. These patients are considered similar to those enrolled in ACS clinical trials examining strategies of routine invasive versus selective invasive (“ischemia-guided”) strategies, such as TACTICS—TIMI 18 (Treat Angina With Aggrastat and Determine the Cost of Therapy With an Invasive or Conservative Strategy—TIMI 18) or ICTUS (Invasive Versus Conservative Treatment in Unstable Coronary Syndromes). Regarding the specifics of the stress testing choices, a wide range of stress testing modalities and timing of stress testing has been reported among numerous randomized trials [68-73]. Thus, we have used the word *stress* generically so as not to create numerous additional categories of exercise (maximal or submaximal) or pharmacologic stress for each modality, and we could not specify optimal timing of testing. It should be assumed that the type of stress used and the timing of testing would not be clinically contraindicated in the specific situation.

Clinical Scenario 8: Any Electrocardiogram and/or Serial Troponins Unequivocally Positive for NSTEMI or ACS. If serial troponins demonstrate positive evidence of myocardial necrosis in the setting of ischemic symptoms or electrocardiographic changes, the diagnosis of NSTEMI or ACS is made, and management can follow existing guidelines [21]. Often this will involve a strategy incorporating catheter angiography and potential

revascularization, as numerous randomized trials have shown that patients with biomarker-positive NSTEMI or ACS generally have more favorable outcomes when managed with an “invasive strategy” consisting of invasive angiography followed by revascularization. Thus, CCath is considered appropriate in this scenario. However, for NSTEMI patients in the presence of certain comorbidities, particularly abnormal renal function, the outcome benefit of a direct invasive angiography and revascularization strategy compared with a “conservative” strategy narrows [74]. In clinical trials of patients with ACS that have randomized patients to either an “invasive” or a “conservative” initial strategy (now also referred to in guidelines as an “ischemia-guided” strategy), the conservative strategy usually consists of stress testing with imaging, often stress SPECT, to assess the presence and extent of ischemia [68,69]. Although many, but not all, such trials showed an outcome advantage for the routine invasive strategy, it is also recognized that in real life, many patients covered by this indication may have comorbidities that might have excluded them from the randomized control trials, such as renal dysfunction mentioned previously, or may be elderly or frail, or simply would prefer a potentially less aggressive management direction. In these situations, clinical consideration could be given to an ischemia-guided strategy, using stress testing with or without imaging, to identify those patients with very extensive ischemia who might have a larger benefit from revascularization, while others could be treated medically. Because these scenarios generally fall outside of the clinical trials, the rating panel did not come to consensus on the alternative strategies besides invasive catheterization, and thus all are rated as “may be appropriate.”

Clinical Scenario 9: Serial ECG and Troponins Negative for NSTEMI or ACS. Patients in this scenario have no evidence of myocardial necrosis. The diagnosis of NSTEMI is ruled out, and the remaining diagnostic considerations include the possibility of troponin-negative unstable angina and CP not due to an ACS. It is in this situation that stress testing to assess for the induction of inducible ischemia is useful (all rest and stress studies are appropriate), as is imaging for anatomic CAD (CCTA is appropriate). Exercise electrocardiographic testing is also appropriate if it is anticipated that the patient can attain an adequate level of exercise stress and if the electrocardiogram is interpretable for stress-induced ischemia. As these tend to be low-risk patients, particularly in the setting of low pretest probability of ACS [75,76], outpatient testing can be considered.

Clinical Scenario 10: Serial ECG or Troponins Borderline for NSTEMI or ACS. Because the assays for troponin have varying precision, at times, results are reported that are detectable but not clearly elevated in a manner consistent with NSTEMI [77]. In such a scenario, NSTEMI has neither been completely ruled in nor ruled out, and further testing is indicated. In this situation, stress testing for inducible ischemia or anatomic testing for the presence of CAD are appropriate, with all rest and stress studies as well as CCTA being considered appropriate.

Description of Diagnostic Studies

Exercise ECG Without Imaging. For low-risk patients with interpretable electrocardiograms, stress ECG without imaging has been reported to be associated with a decrease in unnecessary admissions [21,76,78,79]. The excellent NPV of 98% to 99% has been confirmed, although the PPV is limited for obstructive CAD [80-87]. The lower PPV may be due to the lower risk population being studied. Use of the Duke treadmill score reduces the false-positive rate of exercise electrocardiographic testing rather than relying on ST-segment changes alone [88-91]. Patients with normal stress test results at a high level of exertion have an excellent prognosis and can be safely discharged [92]. Thus, for patients with normal results on ECG and the ability to exercise adequately, stress tests without imaging can be useful [17]. For patients with potentially uninterpretable stress electrocardiograms (left ventricular hypertrophy with secondary ST-T changes, paced rhythms, left bundle branch block) or those who do not achieve an adequate stress heart rate, stress ECG will not be useful.

Stress Echocardiography. Stress echocardiography may involve exercise or pharmacologic (dobutamine or atropine) stress, and it increases myocardial oxygen consumption such that the presence of a flow-limiting lesion will impair perfusion and create segmental systolic and diastolic dysfunction in the underperfused region. The presence and extent of an induced wall motion abnormality are more sensitive and specific than stress-induced electrocardiographic abnormalities alone [81,82,86] and have higher NPV for excluding obstructive CAD [93-97]. Achievement of an adequate heart rate/demand response from exercise or from dobutamine stress is important to optimize sensitivity to detect underlying CAD. Thus, if exercise or tachycardic stress is felt to be clinically contraindicated, pharmacologic vasodilator stress with myocardial perfusion imaging by SPECT or CMR would be preferable. Visualization of endocardial borders for all

myocardial segments is a prerequisite for optimal test accuracy. Stress echocardiography also detects the presence of prior infarction and provides information about cardiac hemodynamics, structure, and function.

Stress SPECT and PET. Stress myocardial perfusion imaging, with exercise or pharmacologic stress, may be used to detect the presence and extent of inducible perfusion abnormalities suggestive of ischemia, as well as the presence of prior infarction. Perfusion may be assessed with the use of widely available SPECT tracers and cameras or may be performed using PET imaging if tracers, equipment, and expertise are available. PET imaging may be useful in patients with larger body mass indexes because of its inherently better spatial resolution. Electrocardiographically gated SPECT or PET acquisition allows simultaneous evaluation of regional and global left ventricular function for this population [98,99]. NPV is also high (96%-100%). The annualized event rate after normal results on stress SPECT is low over follow-up [40,87,98-100].

Stress CMR. A small randomized trial assessed outcomes and costs in patients with suspected ACS and intermediate likelihood of CAD randomized to an observation unit strategy of serial biomarkers followed by adenosine stress CMR compared with an inpatient evaluation strategy [101]. There were no differences in missed ACS from the index visit and no differences in outcome events between the two strategies over one year [102]. Costs associated with the index visit, as well as costs out to one year of follow-up were lower with the observation unit/stress CMR strategy. These investigators reported, however, that among low-risk patients, a mandated CMR strategy incurred higher costs than a “provider-directed” imaging strategy, in which clinicians most often chose stress echocardiography [103].

SECTION 3: IMAGING OF PATIENTS WITH SUSPECTED PE

Clinical Rationale

Venous thromboembolic disease includes both PE and deep venous thrombosis (DVT). PE accounts for 100,000 to 180,000 deaths annually in the United States and afflicts millions of individuals worldwide. The 15% case fatality rate for PE exceeds the mortality rate for AMI [104,105]. PE survivors may have impaired quality of life due to chronic thromboembolic pulmonary hypertension.

PE affects patients of widely varying ages, from teenagers to the elderly. Its onset is usually unpredictable, but

associated risk factors may include prolonged immobility, trauma, recent surgery, cancer, oral contraceptive use, pregnancy, and postmenopausal hormone replacement.

Clinicians must remain vigilant to detect PE because of the diverse presenting signs and symptoms. For example, PE can present like other illnesses, such as pneumonia and congestive heart failure.

ECG is insensitive for PE but may raise suspicion or help confirm the diagnosis in patients with electrocardiographic manifestations of right-heart strain. Right-heart strain, however, may not be present, is not specific, and may be observed in patients with asthma, idiopathic pulmonary hypertension, or other etiologies of cor pulmonale. Patients with massive PE may have sinus tachycardia, slight ST- and T-wave abnormalities, or even entirely normal findings on ECG [106]. Other abnormalities include incomplete or complete right bundle branch block and an S1Q3T3 complex. T-wave inversion in leads V₁ to V₄ has the greatest accuracy for identifying right ventricular dysfunction in patients with acute PE.

The results of echocardiography are normal in about half of unselected patients with acute PE [107], and thus it was not considered by the rating panel for the diagnosis of PE. However, positive findings such as elevated right ventricular systolic pressure, a dilated right ventricle, and a hypokinetic right ventricle with apical sparing [108] can raise suspicion for PE. More important, echocardiography with supporting biomarkers can identify those patients with potentially poor prognoses and thus guide management [104,109,110]. For those patients, echocardiography is an important “second” examination; the role of echocardiography for prognosis is beyond the scope of this document.

Imaging Rationale

Chest radiography is insensitive to PE and was not rated. However, radiography plays a major role in initial patient management and exclusion of competing disease conditions. Major chest x-ray abnormalities are uncommon in PE. Focal oligemia (Westermark sign) may indicate massive central embolic occlusion [111]. A peripheral wedge-shaped density above the diaphragm (Hampton hump) usually indicates pulmonary infarction [112], but this finding is uncommon. Subtle abnormalities suggestive of PE include enlargement of the descending right pulmonary artery. The vessel often tapers rapidly after the enlarged portion. For patients who are not pregnant, the following three clinical scenarios were considered by the rating panel. Two additional scenarios were considered for patients who are pregnant (Table 3).

Table 3. Suspected PE

Indication	CTPA	CompUS	VQ	PMRA	PCath
Likelihood by clinical scoring algorithm alone, patient not pregnant					
11. D-dimer negative Not high likelihood by a clinical scoring algorithm	R	R	R	R	R
12. D-dimer positive Not high likelihood by a clinical scoring algorithm	A	M	A	R	R
13. High likelihood by a clinical scoring algorithm	A	A	A	R	R
Pregnancy					
14. Patient with leg symptoms	M*	A	A	R	R
15. Patient with no leg symptoms	A	M*	A	R	R

Appropriate use key: A = appropriate; M = may be appropriate with rating panel consensus; M* = may be appropriate as determined by lack of consensus by rating panel; R = rarely appropriate.

CTPA = CT pulmonary angiography; CompUS = compression ultrasonography of the deep veins; PCath = catheter-based pulmonary angiography; PMRA = pulmonary MR angiography; VQ = ventilation-perfusion scan.

Description of Clinical Scenarios

Clinical Scenario 11: D-Dimer Negative and Not High Likelihood by a Clinical Scoring Algorithm.

When the clinical likelihood of DVT and PE, on the basis of clinical probability scoring systems such as the Wells criteria [113-115] or revised Geneva score [116,117], is low and the results of plasma D-dimer assay [118] are normal, the exclusion of PE is usually straightforward and accurate [119,120]. In this scenario, all imaging modalities under consideration are considered rarely appropriate.

Clinical Scenario 12: D-Dimer Positive and Not High Likelihood by a Clinical Scoring Algorithm.

CTPA has supplanted ventilation-perfusion scan (VQ) as the initial study to confirm or exclude clinically suspected PE [121-123]. Both are considered appropriate studies for this scenario. PCath, once considered the reference standard, has been shown to be less useful as the initial examination [124], although it is used in planning intervention. The rating panel did not consider the role of catheterization for the intervention itself.

Clinical Scenario 13: High Likelihood by a Clinical Scoring Algorithm.

The rating panel considered high-risk patients, independent of D-dimer, as a separate scenario. The panel also considered that some patients in this group may not be hemodynamically stable. CTPA, VQ, and compression ultrasonography of the deep veins (CompUS) are all appropriate initial studies.

Description of Imaging Modalities

CTPA. Multidetector-row CT scanners rapidly image the entire chest with high spatial resolution [121-123,125,126], and extant guidelines [120,127] have demonstrated CTPA as a useful diagnostic strategy to exclude or confirm the presence

of a filling defect in a patient for whom there is clinical suspicion for PE. In a meta-analysis of 3,500 patients undergoing CTPA and followed for at least three months, the overall NPV of CT was 99.4% [128]. A validated outcome strategy is D-dimer testing followed by CTPA for patients with abnormally elevated D-dimer levels. Using this strategy, only 1.5% of patients with negative findings developed DVT or PE during 3-month follow-up [129]. A systematic review of management outcome studies showed that patients with low or moderate pretest probability and normal D-dimer levels had a very low 3-month thromboembolism rate [130]. CTPA also identifies other pulmonary diseases, including pneumonia, atelectasis, pneumothorax, and pleural effusion, that might not be well visualized on chest radiography.

The latest generation scanners can image thrombus in sixth-order vessels [131]. These thrombi are so tiny that their clinical significance is uncertain [132]. The presence of right-heart strain is a poor prognostic factor for patients with PE; therefore, the interpreter should compare the size of the right ventricle with that of the left ventricle in positive cases [133], as a normal right ventricle's diameter is smaller than that of the left ventricle.

CTPA using rapid imaging protocols can include additional scanning to identify DVT in the subclavian veins and other major upper extremity veins that might contain thrombi and serve as the source of PE. Although protocols have been developed and tested for imaging the venous system in the abdomen, pelvis, thighs, and knees for pelvic vein thrombosis and proximal leg DVT [134], CT venography is not routinely used at the time of pulmonary angiography, as it increases radiation exposure and rarely changes clinical management [131,135,136]. Combined CTPA and CT venography were not considered by the rating panel.

The accuracy of CT is lower when the imaging results and clinical probability assessment are discordant, particularly

in those patients with negative results on CT but high clinical probability of PE, even though this group constituted only 3% of the PIOPED (Prospective Investigation of Pulmonary Embolism Diagnosis) II cohort [134]. This finding was similar to the initial PIOPED study, which focused on pulmonary scintigraphy [137]; therefore, clinicians should be cautious in the unusual circumstance in which imaging results are discordant with clinical likelihood of PE.

Pulmonary Scintigraphy/VQ. Nuclear lung scans use radiolabeled aggregates of albumin or microspheres that lodge in the pulmonary microvasculature. Patients with large PEs have multiple perfusion defects. If ventilation scanning is performed on a patient with PE but no intrinsic lung disease, a normal ventilation study result is expected, yielding a ventilation-perfusion mismatch. This combination of findings is interpreted as indicative of high probability for PE. The initial PIOPED study showed that, of the small minority of patients with low-probability scans but high clinical suspicion for PE, up to 40% will have PE proved by PCath [137]. PE is unlikely in patients with low-probability VQ combined with low-probability clinical assessment. Conversely, a high-probability VQ combined with a high-probability clinical assessment is highly predictive of PE. With other combinations, further evaluation is often needed.

Pulmonary MR Angiography. Although single-center studies of gadolinium-enhanced MR angiography have been promising [138-140], the PIOPED III study demonstrated a lack of sensitivity to detect PE [141].

PCath. Invasive pulmonary angiography was a former reference standard for the diagnosis of PE. It has a small but defined risk for major complications [142], and reliably identifying smaller filling defects can be difficult [124]. Although the rating of catheter angiography as part of PE treatment is beyond the scope of this document, it is required when interventions—such as suction catheter embolectomy, mechanical clot fragmentation, or catheter-directed thrombolysis—are planned.

CompUS. CompUS is appropriate to evaluate the lower extremity deep venous system in high-risk patients, particularly those with leg symptoms. Compression is used to confirm the presence or absence of DVT. However, at least half of patients with PE have no imaging evidence of DVT.

SUSPECTED PE IN PREGNANCY

Imaging Rationale

In pregnancy, D-dimer testing is of limited use to exclude PE [143]. Pregnant women with suspected PE are divided into

those with DVT symptoms in the legs and those without such symptoms. Although most pregnant women with clinical suspicion do not have leg symptoms [144,145], CompUS does not deliver ionizing radiation, and when there are signs and symptoms of DVT, a positive result may eliminate the need for further testing that uses ionizing radiation [146]. Current guidelines suggest that chest radiography can be used to suggest an initial test [146], but because x-ray findings do not confirm or exclude PE, chest radiography was not considered by the rating panel.

Pulmonary MR angiography generally requires the use of gadolinium and is strongly contraindicated in pregnancy. There are emerging MR methods that do not use gadolinium, but because these are limited to specialized centers, they were not considered by the rating panel. PCath is also contraindicated because of the contrast and radiation burden.

Description of Clinical Scenarios

Clinical Scenario 14: Pregnant Patient With Leg Symptoms.

For hemodynamically stable pregnant patients with suspected PE and signs and/or symptoms of DVT, CompUS is an appropriate initial study because it delivers neither ionizing radiation nor intravenous contrast material. VQ was also considered appropriate, and CTPA may be appropriate.

Clinical Scenario 15: Pregnant Patient With No Leg Symptoms.

For patients with no signs and symptoms of DVT and for whom clinical suspicion warrants an imaging study, both CTPA and VQ are appropriate initial examinations. Of note, when scintigraphy is performed, lung perfusion can be done as the initial study, and if the results are normal, the ventilation portion of the examination can be averted. CompUS may be appropriate.

SECTION 4: IMAGING OF PATIENTS WITH SUSPECTED ACUTE SYNDROMES OF THE AORTA

Clinical Rationale

Aortic dissection is a common pathology among the AAS; the other diagnoses include penetrating ulcer, intramural hematoma, and unstable thoracic aortic aneurysm. These diagnoses are challenging, in part because patients may have no apparent risk factors for the condition; another reason is that the clinical presentation is quite variable and therefore not readily recognized. However, because these diagnoses, including acute aortic dissection, are life threatening, with an early mortality rate of as high as 1% to 2% per hour, a high suspicion for the diagnosis and prompt

Table 4. Suspected AAS

Indication	CTAo	MRAo	TTE	TEE	AoCath
Hemodynamically unstable patient					
16. Prior or no prior aorta intervention	A	M*	M*	M*	M*
Hemodynamically stable patient					
17. No prior aorta intervention	A	A	M	A	R
18. Prior aorta intervention	A	A	M	M*	M*

Appropriate use key: A = appropriate; M = may be appropriate with rating panel consensus; M* = may be appropriate as determined by lack of consensus by rating panel; R = rarely appropriate.

AoCath = catheter-based aortography; CTAo = CT aortography; MRAo = MR aortography; TEE = transesophageal echocardiography; TTE = transthoracic echocardiography.

diagnostic evaluation are keys to a timely diagnosis and a favorable outcome. In the acute setting, chest radiography is commonly performed, primarily to identify other causes of a patient's symptoms but also to screen for a dilated aorta or evidence suggestive of bleeding. Normal results on chest radiography do not exclude an AAS [147], and radiography was not considered by the rating panel.

The presence of any of the known risk factors for aortic dissection in a patient with acute pain should heighten suspicion of aortic dissection and other AAS such as intramural hematoma [148]; these risk factors include a known thoracic aortic aneurysm, connective tissue disorders that result in aortic medial degeneration (eg, Marfan syndrome, vascular Ehlers-Danlos syndrome, Loeys-Dietz syndrome), a bicuspid aortic valve, family history of thoracic aortic aneurysms or dissection, advanced age, male gender, and a long-standing history of hypertension. However, the absence of these risk factors should not deter the ED physician from pursuing the diagnosis.

Unlike the pain associated with ACS, the pain of aortic dissection is usually of sudden onset (rather than a crescendo), severe, and sharp or stabbing and frequently radiates to the back or left shoulder. Patients often present with abnormal hemodynamic status, either hypertension or hypotension. There is no specific biomarker for the detection of aortic dissection, and although D-dimer levels are significantly elevated in most cases of acute dissection [149], D-dimer is generally not used in a decision algorithm that includes imaging. Thus, the definitive diagnosis of aortic dissection requires dedicated imaging of the aorta.

Imaging Rationale

Selection of the most appropriate imaging study for diagnosis and evaluation of an AAS depends on patient-related factors and the probability of an aortic syndrome versus other explanations for a patient's clinical presentation [150]. The main distinction considered by the panel was patient hemodynamic stability (Table 4).

Even for a relatively unstable patient who is being strongly considered for intervention such as surgery, anatomic imaging with CT is important for planning the procedure [151,152]. However, patients with type A dissection can present with hemopericardium, and there is a distinction in these patients regarding an assessment of the pericardium as the first imaging study that can then be used to guide emergent evacuation of the pericardium.

Description of Clinical Scenarios

Clinical Scenario 16: Hemodynamically Unstable Patient, Regardless of Prior Aortic Intervention. In this scenario, hemopericardium with subsequent tamponade is a strong clinical concern. Imaging of the full anatomy with CTAo, after stabilization, is considered appropriate. All other studies may be appropriate and will be guided by the presentation and the degree of hemodynamic instability. For example, in the scenario of a patient too unstable to be transported and imaged in a CT scanner, a bedside test such as TEE may be quite appropriate and provide comprehensive and critical information regarding the underlying cause of the instability.

Clinical Scenario 17: Hemodynamically Stable Patient, No Prior Aorta Intervention. This scenario accounts for the large majority of patients with suspected aortic dissection for whom imaging is performed. CTAo, MR aortography (MRAo), and transesophageal echocardiography (TEE) are considered appropriate.

Clinical Scenario 18: Hemodynamically Stable Patient, Prior Aorta Intervention. In this scenario, the patient is stable, but a complication of the surgical or percutaneous intervention such as a pseudoaneurysm is important in the differential diagnosis. CTAo and MRAo are both appropriate, although artifacts in MR images may be challenging. The other studies may be appropriate; in

particular, echocardiography may have interference, as the prior intervention often includes metal that causes artifacts.

Description of Imaging Modalities

CTAo. CTAo rapidly images the entire aorta and its branches and identifies specific AAS. Multiplanar and 3-D image reformations can be used to plan interventions. Electrocardiographically gated techniques facilitate motion-free images of the aortic root and coronary arteries. Modern CTAo has very high accuracy for life-threatening pathology of the aorta [153,154]. Although unenhanced imaging [155] can identify findings of AAS, dedicated CTAo is used when there is a clinical suspicion for AAS, and the rating panel considered only contrast-enhanced CT.

MRAo. MR is very accurate, with sensitivities and specificities essentially equivalent to those of CT. Like CT, advantages of MR include the ability to image the entire vascular system, to identify anatomic variants of aortic dissection, and to display the aorta and branch vessels in multiple planes and three dimensions. In addition, MR can diagnose concomitant aortic valve pathology and evaluate left ventricular function. Disadvantages include prolonged duration of imaging acquisition, during which the patient is relatively inaccessible to care providers. For this reason, MR can be limited for patients who are not hemodynamically stable. Other relative contraindications are noted for patients with claustrophobia and those with either metallic implants or pacemakers. Noncontrast MR techniques are emerging as a method to provide good-quality MR angiographic images without contrast. However, because these methods are limited to research studies and large academic centers, the rating panel considered only contrast-enhanced MR.

Transthoracic Echocardiography. The advantage of echocardiography is the ability to image at the bedside when a patient is relatively unstable to undergo CT. The main use of transthoracic echocardiography (TTE) is to assess the pericardium and provide dynamic information on valve (eg, the presence or absence of aortic regurgitation) and ventricular function. TTE has limitations [156] compared with TEE for visualizing an intimal flap because it can be difficult to obtain an acoustic window to assess the full extent of the aorta. Moreover, the frequent appearance of artifacts that mimic a dissection flap can arise from a mirror image or reverberation artifact that appears as a mobile linear echo density overlying the aortic lumen. The operator must make certain to distinguish any artifact from a true dissection flap.

TEE. TEE provides a superior assessment of the visualized aorta and the aortic valves compared with TTE

[156,157]. Like TTE, TEE can be performed at the bedside. The main limitation is difficulty in evaluating the length of the aorta and all branch vessels in three dimensions. Obtaining high-quality transesophageal echocardiographic images of the arch behind the trachea can be technically challenging. TEE is also relatively invasive and is contraindicated in patients with some pharyngeal and esophageal abnormalities.

AoCath. AoCath was once considered the reference standard for diagnosis of the aorta, including aortic dissection, penetrating ulcer, and unstable aneurysm [158-160]. Although beyond the scope of this document and not considered by the rating panel, catheter-based approaches are now used to manage AAS patients [161], and in this setting diagnostic AoCath is performed.

SECTION 5: IMAGING OF PATIENTS FOR WHOM A LEADING DIAGNOSIS IS PROBLEMATIC OR NOT POSSIBLE

Clinical Rationale

CP patients who present to the ED with complex patterns of signs, symptoms, and clinical data (eg, laboratory assessment, ECG) can undergo a variety of imaging strategies. The ED physician typically places such patients into one of the three diagnostic pathways as detailed in sections 2 to 4. It is also assumed that alternative imaging pathways may be necessary if the initial, tentative diagnosis is not confirmed. For this reason, such complex patients often undergo more than one imaging study to arrive at a diagnosis or to exclude all diagnoses considered to be life threatening. As noted previously, this document does not consider a “second” imaging study, as there are very few data and the choice of the second study may be influenced by the findings of the first.

Imaging Rationale and Description of Imaging

Another option is to implement so-called TRO CT angiography (CTA) [162,163] to potentially evaluate or exclude CAD, PE, and aortic disease in a single examination [164,165]. Initial, small, single-center studies have reported an NPV (final diagnosis is the reference) of 99.4% to 100%, and image quality and diagnostic accuracy have reports that are equivalent to dedicated CCTA, CTPA, and CTAo [164-166].

The majority of published studies have performed TRO CTA by modifying a coronary CT protocol to image more of the chest (either from the aortic arch to the base or the entire chest) and using additional contrast to maintain pulmonary artery enhancement, resulting in reported increases in

Table 5. Imaging of Patients for Whom a Leading Diagnosis is Problematic or Not Possible

Indication	"Triple-Rule-Out" CTA
19. Overall likelihood of ACS, PE, or AAS is low	R
20. Overall likelihood of ACS, PE, or AAS is not low	A

Appropriate use key: A = appropriate; R = rarely Appropriate. AAS = acute aortic syndrome; ACS = acute coronary syndrome; CTA = CT angiography; PE = pulmonary embolism.

radiation dose from 25% to 150% and in contrast volume from 20% to 50%. For these reasons, dedicated CT imaging is preferred when the differential diagnosis can be narrowed. However, large-volume detectors [167] and high-pitch, helical, dual-source CT [168] may reduce the radiation and contrast dose penalties of TRO CTA, potentially allowing more widespread application [169]. The rating panel considered two scenarios for those patients who could be considered for TRO CTA (Table 5).

Description of Scenarios

Clinical Scenario 19: Overall Likelihood of ACS, PE, or AAS Is Low. The increased diagnostic yield of a TRO study over dedicated coronary CT is quite small, and when the overall likelihood of both PE and AAS is low, TRO CTA is considered rarely appropriate.

Clinical Scenario 20: Overall Likelihood of ACS, PE, or AAS Is Not Low. TRO CTA is considered appropriate in patients for whom the overall likelihood of ACS, PE, or AAS is not low. As CT technology continues to improve, additional studies are anticipated that will simultaneously assess the coronary plus pulmonary arteries as well as the aorta.

PRESIDENT AND STAFF

ACR Board of Chancellors Chair and Staff

Bibb Allen Jr, MD, FACR, Chair, Board of Chancellors
William T. Thorwarth Jr, MD, FACR, Chief Executive Officer

Pamela A. Wilcox, RN, MBA, Executive Vice President for Quality and Safety

David Kurth, MPH, MA, Director, Practice Parameters, Appropriateness Criteria

Christine Waldrip, RN, MSA, Manager, Appropriateness Criteria

Makeba Scott Hunter, Managing Editor, *Journal of the American College of Radiology*

American College of Cardiology President and Staff

Kim A. Williams, MD, MACC, President
Shalom Jacobovitz, Chief Executive Officer

William J. Oetgen, MD, MBA, FACC, Executive Vice President, Science, Education, Quality, and Publications
Joseph M. Allen, MA, Team Leader, Clinical Policy and Pathways

Z. Jenissa Haidari, MPH, CPHQ, Team Leader, Appropriate Use Criteria

María Velásquez, Senior Research Specialist, Appropriate Use Criteria

Amelia Scholtz, PhD, Publications Manager, Clinical Policy and Pathways

APPENDIX 1: ABBREVIATIONS

AAS = acute aortic syndrome

ACS = acute coronary syndrome

AMI = acute myocardial infarction

AoCath = catheter-based aortography

CAD = coronary artery disease

CCath = catheter-based coronary angiography

CCTA = coronary CT angiography

CMR = cardiovascular MR

CompUS = compression ultrasonography of the deep veins

CP = chest pain

CTA = CT angiography

CTAo = CT aortography

cTn = cardiac troponin

CTPA = CT pulmonary angiography

ECG = electrocardiography

DVT = deep venous thrombosis

ED = emergency department

FOCUS = focused cardiac ultrasound

MACE = major adverse cardiovascular event

MI = myocardial infarction

MRAo = MR aortography

NPV = negative predictive value

NSTEMI = non-ST-segment elevation myocardial infarction

PCath = catheter-based pulmonary angiography

PE = pulmonary embolism

PPV = positive predictive value

SPECT = single-photon emission computed tomography

STEMI = ST-segment elevation myocardial infarction

TEE = transesophageal echocardiography

TIMI = Thrombolysis in Myocardial Infarction

TRO = triple-rule-out

TTE = transthoracic echocardiography

VQ = ventilation-perfusion scan

APPENDIX 2: ACR/ACC/AHA/AATS/ACEP/ASNC/NASCI/SAEM/SCCT/SCMR/SCPC/SNMMI/STR/STS 2015 Appropriate Utilization of Cardiovascular Imaging in Emergency Department Patients With CP Writing Group, Rating Panel, Task Force, and Indication Reviewers—Relationships With Industry and Other Entities (Relevant)

A standard exemption to the American College of Cardiology's policy regarding relationships with industry is extended to appropriate use criteria writing committees that do not make recommendations but rather prepare background materials and typical clinical scenarios and indications that are rated independently by a separate rating panel.

Participant	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Appropriate Utilization of Cardiovascular Imaging in ED Patients With CP Writing Group						
Frank J. Rybicki	None	None	None	<ul style="list-style-type: none"> ■ Toshiba Medical Systems* 	None	None
James E. Udelson	None	None	None	None	None	None
W. Frank Peacock	<ul style="list-style-type: none"> ■ Alere ■ BG Medicine ■ Cardiorentis* ■ Daiichi-Sankyo ■ Instrumentation Laboratories ■ Janssen ■ The Medicine's Company ■ Novartis 	None	<ul style="list-style-type: none"> ■ Comprehensive Research Associates* 	<ul style="list-style-type: none"> ■ Alere ■ Critical Diagnostics ■ The Medicine's Company* ■ Roche* 	None	None
Samuel Z. Goldhaber	<ul style="list-style-type: none"> ■ Bayer ■ BMS ■ Boehringer Ingelheim ■ Daiichi -Sankyo* ■ Janssen ■ Merck ■ Pfizer ■ Portola 	None	None	<ul style="list-style-type: none"> ■ BMS* ■ BTG* ■ Daiichi -Sankyo* ■ NHLBI* ■ Thrombosis Research Institute 	None	None
Eric M. Isselbacher	None	None	None	None	None	None
Ella Kazerooni	None	None	None	None	None	None
Michael C. Kontos	None	None	None	None	None	None
Harold Litt	<ul style="list-style-type: none"> ■ HeartFlow, Inc 	None	None	<ul style="list-style-type: none"> ■ Siemens Medical Solutions 	None	None
Pamela K. Woodard	None	None	None	None	None	None
Appropriate Utilization of Cardiovascular Imaging in ED Patients With CP Rating Panel						
Joseph S. Alpert	None	None	None	None	None	None
George A. Andrews	None	None	None	None	<ul style="list-style-type: none"> ■ Humana, Inc (employee)* 	None
Edward P. Chen	<ul style="list-style-type: none"> ■ Medtronic 	None	None	None	None	None
David T. Cooke	None	None	None	None	None	None

(continued)

Continued

Participant	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Ricardo C. Curry	<ul style="list-style-type: none"> ■ Astellas* ■ GE Healthcare* 	None	None	<ul style="list-style-type: none"> ■ Astellas* ■ GE Healthcare* 	None	None
Daniel Edmundowicz	None	None	None	None	None	None
Victor Ferrari	None	None	None	None	<ul style="list-style-type: none"> ■ Society for Cardiovascular Magnetic Resonance 	None
Louis G. Graff	None	None	None	None	None	None
Judd E. Hollander	<ul style="list-style-type: none"> ■ Behring ■ Instrumentation Laboratories ■ Janssen ■ Radiometer* 	None	None	<ul style="list-style-type: none"> ■ Abbott* ■ Alere* ■ Brahms* ■ Siemens* 	None	None
Lloyd W. Klein	None	None	None	None	None	None
Jonathan Leipsic	<ul style="list-style-type: none"> ■ Edwards* ■ GE Healthcare 	<ul style="list-style-type: none"> ■ GE Healthcare 	None	<ul style="list-style-type: none"> ■ Heartflow* 	None	None
Phillip D. Levy	None	None	None	None	<ul style="list-style-type: none"> ■ Lantheus Medical Imaging ■ National Institutes of Health* 	None
John J. Mahmarian	None	None	None	None	None	None
Craig Rosenberg	None	None	None	None	None	None
Geoffrey Rubin	None	None	None	None	None	None
R. Parker Ward	None	None	None	None	None	None
Charles White	None	None	None	None	None	None
Appropriate Utilization of Cardiovascular Imaging in ED Patients With CP External Reviewers						
Fabian Bamberg	None	<ul style="list-style-type: none"> ■ Bayer ■ Siemens 	None	None	None	None
Dickson S. Cheung	None	None	None	None	None	None
Jersey Chen	None	None	None	None	<ul style="list-style-type: none"> ■ Agency for Healthcare Quality and Research 	None
Resa Lewiss	None	None	None	None	None	None
Michel Makaroun	None	None	None	None	None	None
James McCord	None	None	None	<ul style="list-style-type: none"> ■ Roche* 	<ul style="list-style-type: none"> ■ Society of CP Centers 	None
Indu G. Poornima	None	None	None	<ul style="list-style-type: none"> ■ Astellas Pharma* ■ GE Healthcare* 	None	None
Gilbert L. Raff	None	None	None	<ul style="list-style-type: none"> ■ Siemens 	None	None
Leslee Shaw	<ul style="list-style-type: none"> ■ Agency for Healthcare Quality and Research 	None	None	None	None	None

(continued)

Continued

Participant	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Todd C. Villiness	None	None	None	None	None	None
ACR Appropriate Utilization of Cardiovascular Imaging Oversight Committee						
E. Kent Yucel	None	None	None	None	None	None
J. Jeffrey Carr	None	None	None	None	■ Society of Cardiovascular Computed Tomography	None
Frank J. Rybicki	None	None	None	None	None	None
Richard D. White	None	None	None	None	None	None
Pamela K. Woodard	None	None	None	■ Astellas*	■ Agency for Healthcare Quality and Research	None
ACC Appropriate Utilization of Cardiovascular Imaging Oversight Committee						
Manesh R. Patel	None	None	None	None	None	None
Pamela S. Douglas	None	None	None	None	None	None
Robert C. Hendel	None	None	None	None	None	None
Christopher M. Kramer	■ St. Jude Medical	None	None	None	None	None
John U. Doherty	None	None	None	None	None	None

This table represents the relevant relationships with industry and other entities that were disclosed by participants at the time of participation. It does not necessarily reflect relationships with industry at the time of publication. A person is deemed to have a significant interest in a business if the interest represents ownership of 5% or more of the voting stock or share of the business entity or ownership of \$10,000 or more of the fair market value of the business entity or if funds received by the person from the business entity exceed 5% of the person's gross income for the previous year. A relationship is considered to be modest if it is less than significant under the preceding definition. Relationships in this table are modest unless otherwise noted. Names are listed in alphabetical order within each category of review. Participation does not imply endorsement of this document.

*Significant (greater than \$10,000) relationship.

REFERENCES

- National Center for Health Statistics. National Hospital Ambulatory Medical Care Survey: 2010 emergency department summary tables. Available at: http://www.cdc.gov/nchs/data/ahcd/nhamcs_emergency/2010_ed_web_tables.pdf. Accessed July 8, 2015.
- Fitch K. The RAND/UCLA appropriateness method user's manual. Santa Monica, CA: RAND; 2001.
- Carr JJ, Hendel RC, White RD, et al. 2013 appropriate utilization of cardiovascular imaging: a methodology for the development of joint criteria for the appropriate utilization of cardiovascular imaging by the American College of Cardiology Foundation and American College of Radiology. *J Am Coll Radiol* 2013;10:456-63.
- AQA. AQA principles for appropriateness criteria. 2007. Available at: <http://www.aqaalliance.org/files/AppropriatenessCriteriaPrinciples.doc>. Accessed July 8, 2015.
- Kumamaru KK, Hoppel BE, Mather RT, Rybicki FJ. CT angiography: current technology and clinical use. *Radiol Clin North Am* 2010;48:213-35.
- Einstein AJ. Effects of radiation exposure from cardiac imaging: how good are the data? *J Am Coll Cardiol* 2012;59:553-65.
- Labovitz AJ, Noble VE, Bierig M, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the American Society of Echocardiography and American College of Emergency Physicians. *J Am Soc Echocardiogr* 2010;23:1225-30.
- Dean AJ, Stahmer SA. Ultrasonography in emergency cardiac care. In: Fields JM, ed. The textbook of emergency cardiovascular care and CPR. Amsterdam, the Netherlands: Wolters Kluwer; 2009:129-48.
- 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;31:550-7.
- Kontos MC. Role of Echocardiography in the emergency department for identifying patients with myocardial infarction and ischemia. *Echocardiography* 1999;16:193-205.
- Peels CH, Visser CA, Kupper AJ, Visser FC, Roos JP. Usefulness of two-dimensional echocardiography for immediate detection of myocardial ischemia in the emergency room. *Am J Cardiol* 1990;65:687-91.
- Sabia P, Afrookteh A, Touchstone DA, Keller MW, Esquivel L, Kaul S. Value of regional wall motion abnormality in the emergency room diagnosis of acute myocardial infarction. A prospective study using two-dimensional echocardiography. *Circulation* 1991;84:185-92.
- Korley FK, Jaffe AS. Preparing the United States for high-sensitivity cardiac troponin assays. *J Am Coll Cardiol* 2013;61:1753-8.
- de Lemos JA. Increasingly sensitive assays for cardiac troponins: a review. *JAMA* 2013;309:2262-9.

15. Cullen L, Mueller C, Parsonage WA, et al. Validation of high-sensitivity troponin I in a 2-hour diagnostic strategy to assess 30-day outcomes in emergency department patients with possible acute coronary syndrome. *J Am Coll Cardiol* 2013;62:1242-9.
16. Otero HJ, Steigner ML, Rybicki FJ. The "post-64" era of coronary CT angiography: understanding new technology from physical principles. *Radiol Clin North Am* 2009;47:79-90.
17. Amsterdam EA, Kirk JD, Bluemke DA, et al. Testing of low-risk patients presenting to the emergency department with chest pain: a scientific statement from the American Heart Association. *Circulation* 2010;122:1756-76.
18. Hoffmann U, Bamberg F, Chae CU, et al. Coronary computed tomography angiography for early triage of patients with acute chest pain: the ROMICAT (Rule Out Myocardial Infarction Using Computer Assisted Tomography) trial. *J Am Coll Cardiol* 2009;53:1642-50.
19. Hoffmann U, Truong QA, Schoenfeld DA, et al. Coronary CT angiography versus standard evaluation in acute chest pain. *N Engl J Med* 2012;367:299-308.
20. Farkouh ME, Aneja A, Reeder GS, et al. Clinical risk stratification in the emergency department predicts long-term cardiovascular outcomes in a population-based cohort presenting with acute chest pain: primary results of the Olmsted county chest pain study. *Medicine* 2009;88:307-13.
21. Amsterdam EA, Wenger NK, Brindis RG, et al. 2014 AHA/ACC guideline for the management of patients with non-ST-elevation acute coronary syndromes: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol* 2014;64:e139-228.
22. Chase M, Robey JL, Zogby KE, Sease KL, Shofer FS, Hollander JE. Prospective validation of the Thrombolysis in Myocardial Infarction risk score in the emergency department chest pain population. *Ann Emerg Med* 2006;48:252-9.
23. Pollack CV Jr, Sites FD, Shofer FS, Sease KL, Hollander JE. Application of the TIMI risk score for unstable angina and non-ST elevation acute coronary syndrome to an unselected emergency department chest pain population. *Acad Emerg Med* 2006;13:13-8.
24. O'Gara PT, Kushner FG, Ascheim DD, et al. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol* 2013;61:e78-140.
25. Antman EM, Anbe DT, Armstrong PW, et al. ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction—executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 1999 Guidelines for the Management of Patients With Acute Myocardial Infarction). *Circulation* 2004;110:588-636.
26. Jayes RL Jr, Beshansky JR, D'Agostino RB, Selker HP. Do patients' coronary risk factor reports predict acute cardiac ischemia in the emergency department? A multicenter study. *J Clin Epidemiol* 1992;45:621-6.
27. Hess EP, Agarwal D, Chandra S, et al. Diagnostic accuracy of the TIMI risk score in patients with chest pain in the emergency department: a meta-analysis. *CMAJ* 2010;182:1039-44.
28. Than M, Cullen L, Reid CM, et al. A 2-h diagnostic protocol to assess patients with chest pain symptoms in the Asia-Pacific region (ASPECT): a prospective observational validation study. *Lancet* 2011;377:1077-84.
29. Than M, Cullen L, Aldous S, et al. 2-Hour accelerated diagnostic protocol to assess patients with chest pain symptoms using contemporary troponins as the only biomarker: the ADAPT trial. *J Am Coll Cardiol* 2012;59:2091-8.
30. Welch RD, Zalenski RJ, Frederick PD, et al. Prognostic value of a normal or nonspecific initial electrocardiogram in acute myocardial infarction. *JAMA* 2001;286:1977-84.
31. Pope JH, Aufderheide TP, Ruthazer R, et al. Missed diagnoses of acute cardiac ischemia in the emergency department. *N Engl J Med* 2000;342:1163-70.
32. Lee TH, Rouan GW, Weisberg MC, et al. Clinical characteristics and natural history of patients with acute myocardial infarction sent home from the emergency room. *Am J Cardiol* 1987;60:219-24.
33. Fram DB, Azar RR, Ahlberg AW, et al. Duration of abnormal SPECT myocardial perfusion imaging following resolution of acute ischemia: an angioplasty model. *J Am Coll Cardiol* 2003;41:452-9.
34. Bavry AA, Kumbhani DJ, Rassi AN, Bhatt DL, Askari AT. Benefit of early invasive therapy in acute coronary syndromes: a meta-analysis of contemporary randomized clinical trials. *J Am Coll Cardiol* 2006;48:1319-25.
35. Bhatt DL, Roe MT, Peterson ED, et al. Utilization of early invasive management strategies for high-risk patients with non-ST-segment elevation acute coronary syndromes: results from the CRUSADE Quality Improvement Initiative. *JAMA* 2004;292:2096-104.
36. Mehta SR, Granger CB, Boden WE, et al. Early versus delayed invasive intervention in acute coronary syndromes. *N Engl J Med* 2009;360:2165-75.
37. 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;288:2693-700.
38. Litt HI, Gatsonis C, Snyder B, et al. CT angiography for safe discharge of patients with possible acute coronary syndromes. *N Engl J Med* 2012;366:1393-403.
39. Kontos MC, Schmidt KL, McCue M, et al. A comprehensive strategy for the evaluation and triage of the chest pain patient: a cost comparison study. *J Nucl Cardiol* 2003;10:284-90.
40. Conti A, Gallini C, Costanzo E, et al. Early detection of myocardial ischaemia in the emergency department by rest or exercise (99m)Tc tracer myocardial SPET in patients with chest pain and non-diagnostic ECG. *Eur J Nucl Med* 2001;28:1806-10.
41. Hilton TC, Fulmer H, Abuan T, Thompson RC, Stowers SA. Ninety-day follow-up of patients in the emergency department with chest pain who undergo initial single-photon emission computed tomographic perfusion scintigraphy with technetium 99m-labeled sestamibi. *J Nucl Cardiol* 1996;3:308-11.
42. Schaeffer MW, Brennan TD, Hughes JA, Gibler WB, Gerson MC. Resting radionuclide myocardial perfusion imaging in a chest pain center including an overnight delayed image acquisition protocol. *J Nucl Med Technol* 2007;35:242-5.
43. Radensky PW, Hilton TC, Fulmer H, McLaughlin BA, Stowers SA. Potential cost effectiveness of initial myocardial perfusion imaging for assessment of emergency department patients with chest pain. *Am J Cardiol* 1997;79:595-9.
44. Stowers SA, Eisenstein EL, Th Wackers FJ, et al. An economic analysis of an aggressive diagnostic strategy with single photon emission computed tomography myocardial perfusion imaging and early exercise stress testing in emergency department patients who present with chest pain but nondiagnostic electrocardiograms: results from a randomized trial. *Ann Emerg Med* 2000;35:17-25.
45. Wackers FJ, Brown KA, Heller GV, et al. American Society of Nuclear Cardiology position statement on radionuclide imaging in patients with suspected acute ischemic syndromes in the emergency department or chest pain center. *J Nucl Cardiol* 2002;9:246-50.
46. Muscholl MW, Oswald M, Mayer C, von Scheidt W. Prognostic value of 2D echocardiography in patients presenting with acute chest pain and non-diagnostic ECG for ST-elevation myocardial infarction. *Int J Cardiol* 2002;84:217-25.
47. Lim SH, Sayre MR, Gibler WB. 2-D echocardiography prediction of adverse events in ED patients with chest pain. *Am J Emerg Med* 2003;21:106-10.
48. Gaibazzi N, Reverberi C, Squeri A, De Iaco G, Ardissino D, Gherli T. Contrast stress echocardiography for the diagnosis of coronary artery disease in patients with chest pain but without acute coronary syndrome: incremental value of myocardial perfusion. *J Am Soc Echocardiogr* 2009;22:404-10.

49. Kaul S, Senior R, Firschke C, et al. Incremental value of cardiac imaging in patients presenting to the emergency department with chest pain and without ST-segment elevation: a multicenter study. *Am Heart J* 2004;148:129-36.
50. Korosoglou G, Labadze N, Hansen A, et al. Usefulness of real-time myocardial perfusion imaging in the evaluation of patients with first time chest pain. *Am J Cardiol* 2004;94:1225-31.
51. Tong KL, Kaul S, Wang XQ, et al. Myocardial contrast echocardiography versus Thrombolysis in Myocardial Infarction score in patients presenting to the emergency department with chest pain and a nondiagnostic electrocardiogram. *J Am Coll Cardiol* 2005;46:920-7.
52. Tsutsui JM, Xie F, O'Leary EL, et al. Diagnostic accuracy and prognostic value of dobutamine stress myocardial contrast echocardiography in patients with suspected acute coronary syndromes. *Echocardiography* 2005;22:487-95.
53. Schenker MP, Dorbala S, Hong EC, et al. Interrelation of coronary calcification, myocardial ischemia, and outcomes in patients with intermediate likelihood of coronary artery disease: a combined positron emission tomography/computed tomography study. *Circulation* 2008;117:1693-700.
54. Beigel R, Oieru D, Goitein O, et al. Usefulness of routine use of multidetector coronary computed tomography in the "fast track" evaluation of patients with acute chest pain. *Am J Cardiol* 2009;103:1481-6.
55. Fazel P, Peterman MA, Schussler JM. Three-year outcomes and cost analysis in patients receiving 64-slice computed tomographic coronary angiography for chest pain. *Am J Cardiol* 2009;104:498-500.
56. 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;49:125-36.
57. Hollander JE, Chang AM, Shofer FS, et al. One-year outcomes following coronary computerized tomographic angiography for evaluation of emergency department patients with potential acute coronary syndrome. *Acad Emerg Med* 2009;16:693-8.
58. 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;115:1762-8.
59. Chang SA, Choi SI, Choi EK, et al. Usefulness of 64-slice multi-detector computed tomography as an initial diagnostic approach in patients with acute chest pain. *Am Heart J* 2008;156:375-83.
60. Goldstein JA, Chinnaiyan KM, Abidov A, et al. The CT-STAT (Coronary Computed Tomographic Angiography for Systematic Triage of Acute Chest Pain Patients to Treatment) trial. *J Am Coll Cardiol* 2011;58:1414-22.
61. Hulten E, Pickett C, Bittencourt MS, et al. Outcomes after coronary computed tomography angiography in the emergency department: a systematic review and meta-analysis of randomized, controlled trials. *J Am Coll Cardiol* 2013;61:880-92.
62. 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;118:837-44.
63. 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;47:1427-32.
64. Kwong RY, Schussheim AE, Rekhraj S, et al. Detecting acute coronary syndrome in the emergency department with cardiac magnetic resonance imaging. *Circulation* 2003;107:531-7.
65. Graff LG, Dallara J, Ross MA, et al. Impact on the care of the emergency department chest pain patient from the Chest Pain Evaluation Registry (CHEPER) study. *Am J Cardiol* 1997;80:563-8.
66. Farkouh ME, Smars PA, Reeder GS, et al. A clinical trial of a chest-pain observation unit for patients with unstable angina. Chest Pain Evaluation in the Emergency Room (CHEER) Investigators. *N Engl J Med* 1998;339:1882-8.
67. Roberts RR, Zalenski RJ, Mensah EK, et al. Costs of an emergency department-based accelerated diagnostic protocol vs hospitalization in patients with chest pain: a randomized controlled trial. *JAMA* 1997;278:1670-6.
68. Cannon CP, Weintraub WS, Demopoulos LA, et al. Comparison of early invasive and conservative strategies in patients with unstable coronary syndromes treated with the glycoprotein IIb/IIIa inhibitor tirofiban. *N Engl J Med* 2001;344:1879-87.
69. de Winter RJ, Windhausen F, Cornel JH, et al. Early invasive versus selectively invasive management for acute coronary syndromes. *N Engl J Med* 2005;353:1095-104.
70. Boden WE, O'Rourke RA, Crawford MH, et al. Outcomes in patients with acute non-Q-wave myocardial infarction randomly assigned to an invasive as compared with a conservative management strategy. Veterans Affairs Non-Q-Wave Infarction Strategies in Hospital (VANQWISH) Trial Investigators. *N Engl J Med* 1998;338:1785-92.
71. Invasive compared with non-invasive treatment in unstable coronary-artery disease: FRISC II prospective randomised multicentre study. Fragmin and Fast Revascularisation During InStability in Coronary Artery Disease Investigators. *Lancet* 1999;354:708-15.
72. Spacek R, Widimsky P, Straka Z, et al. Value of first day angiography/angioplasty in evolving Non-ST segment elevation myocardial infarction: an open multicenter randomized trial. The VINO Study. *Eur Heart J* 2002;23:230-8.
73. Fox KA, Poole-Wilson PA, Henderson RA, et al. Interventional versus conservative treatment for patients with unstable angina or non-ST-elevation myocardial infarction: the British Heart Foundation RITA 3 randomised trial. Randomized Intervention Trial of unstable Angina. *Lancet* 2002;360:743-51.
74. Szummer K, Lundman P, Jacobson SH, et al. Influence of renal function on the effects of early revascularization in non-ST-elevation myocardial infarction: data from the Swedish Web-System for Enhancement and Development of Evidence-Based Care in Heart Disease Evaluated According to Recommended Therapies (SWEDEHEART). *Circulation* 2009;120:851-8.
75. Newby LK, Jesse RL, Babb JD, et al. ACCF 2012 expert consensus document on practical clinical considerations in the interpretation of troponin elevations: a report of the American College of Cardiology Foundation Task Force on Clinical Expert Consensus Documents. *J Am Coll Cardiol* 2012;60:2427-63.
76. Meyer MC, Mooney RP, Sekera AK. A critical pathway for patients with acute chest pain and low risk for short-term adverse cardiac events: role of outpatient stress testing. *Ann Emerg Med* 2006;47:435.
77. Zahid M, Good CB, Singla I, Sonel AF. Clinical significance of borderline elevated troponin I levels across different assays in patients with suspected acute coronary syndrome. *Am J Cardiol* 2009;104:164-8.
78. Kerns JR, Shaub TF, Fontanarosa PB. Emergency cardiac stress testing in the evaluation of emergency department patients with atypical chest pain. *Ann Emerg Med* 1993;22:794-8.
79. Zalenski RJ, McCarren M, Roberts R, et al. An evaluation of a chest pain diagnostic protocol to exclude acute cardiac ischemia in the emergency department. *Arch Intern Med* 1997;157:1085-91.
80. Diercks DB, Kirk JD, Turnipseed SA, Amsterdam EA. Use of additional electrocardiograph leads in low-risk patients undergoing exercise treadmill testing. *Crit Pathw Cardiol* 2006;5:123-6.
81. Jeetley P, Burden L, Senior R. Stress echocardiography is superior to exercise ECG in the risk stratification of patients presenting with acute chest pain with negative Troponin. *Eur J Echocardiogr* 2006;7:155-64.

82. Leischik R, Dworrak B, Littwitz H, Gulker H. Prognostic significance of exercise stress echocardiography in 3329 outpatients (5-year longitudinal study). *Int J Cardiol* 2007;119:297-305.
83. Alvarez Tamargo JA, Martin-Ambrosio ES, Tarin ER, Fernandez MM, De la Tassa CM. Significance of the treadmill scores and high-risk criteria for exercise testing in non-high-risk patients with unstable angina and an intermediate Duke treadmill score. *Acta Cardiol* 2008;63:557-64.
84. Conti A, Vanni S, Sammicheli L, et al. Yield of nuclear scan strategy in chest pain unit evaluation of special populations. *Nucl Med Commun* 2008;29:1106-12.
85. Mollet NR, Cademartiri F, Van Mieghem C, et al. Adjunctive value of CT coronary angiography in the diagnostic work-up of patients with typical angina pectoris. *Eur Heart J* 2007;28:1872-8.
86. Nucifora G, Badano LP, Sarraf-Zadegan N, et al. Comparison of early dobutamine stress echocardiography and exercise electrocardiographic testing for management of patients presenting to the emergency department with chest pain. *Am J Cardiol* 2007;100:1068-73.
87. Candell-Riera J, Oller-Martinez G, de Leon G, Castell-Conesa J, Aguade-Bruix S. Yield of early rest and stress myocardial perfusion single-photon emission computed tomography and electrocardiographic exercise test in patients with atypical chest pain, nondiagnostic electrocardiogram, and negative biochemical markers in the emergency department. *Am J Cardiol* 2007;99:1662-6.
88. Gibbons RJ, Balady GJ, Bricker JT, et al. ACC/AHA 2002 guideline update for exercise testing: summary article. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines). *J Am Coll Cardiol* 2002;40:1531-40.
89. Kligfield P, Lauer MS. Exercise electrocardiogram testing: beyond the ST segment. *Circulation* 2006;114:2070-82.
90. Manini AF, McAfee AT, Noble VE, Bohan JS. Prognostic value of the Duke treadmill score for emergency department patients with chest pain. *J Emerg Med* 2010;39:135-43.
91. Mark DB, Shaw L, Harrell FE Jr, et al. Prognostic value of a treadmill exercise score in outpatients with suspected coronary artery disease. *N Engl J Med* 1991;325:849-53.
92. Roger VL, Jacobsen SJ, Pellikka PA, Miller TD, Bailey KR, Gersh BJ. Prognostic value of treadmill exercise testing: a population-based study in Olmsted County, Minnesota. *Circulation* 1998;98:2836-41.
93. Bedetti G, Pasanisi EM, Tintori G, et al. Stress echo in chest pain unit: the SPEED trial. *Int J Cardiol* 2005;102:461-7.
94. Buchsbaum M, Marshall E, Levine B, et al. Emergency department evaluation of chest pain using exercise stress echocardiography. *Acad Emerg Med* 2001;8:196-9.
95. Trippi JA, Lee KS, Kopp G, Nelson DR, Yee KG, Cordell WH. Dobutamine stress tele-echocardiography for evaluation of emergency department patients with chest pain. *J Am Coll Cardiol* 1997;30:627-32.
96. Orlandini A, Tuero E, Paolasso E, Vilamajo OG, Diaz R. Usefulness of pharmacologic stress echocardiography in a chest pain center. *Am J Cardiol* 2000;86:1247-50.
97. Bholasingh R, Cornel JH, Kamp O, et al. Prognostic value of pre-discharge dobutamine stress echocardiography in chest pain patients with a negative cardiac troponin T. *J Am Coll Cardiol* 2003;41:596-602.
98. Conti A, Zanobetti M, Grifoni S, et al. Implementation of myocardial perfusion imaging in the early triage of patients with suspected acute coronary syndromes. *Nucl Med Commun* 2003;24:1055-60.
99. Kontos MC, Haney A, Ornato JP, Jesse RL, Tatum JL. Value of simultaneous functional assessment in association with acute rest perfusion imaging for predicting short- and long-term outcomes in emergency department patients with chest pain. *J Nucl Cardiol* 2008;15:774-82.
100. Fesmire FM, Hughes AD, Stout PK, Wojcik JF, Wharton DR. Selective dual nuclear scanning in low-risk patients with chest pain to reliably identify and exclude acute coronary syndromes. *Ann Emerg Med* 2001;38:207-15.
101. Miller CD, Hwang W, Hoekstra JW, et al. Stress cardiac magnetic resonance imaging with observation unit care reduces cost for patients with emergent chest pain: a randomized trial. *Ann Emerg Med* 2010;56:209-19.
102. Miller CD, Hwang W, Case D, et al. Stress CMR imaging observation unit in the emergency department reduces 1-year medical care costs in patients with acute chest pain: a randomized study for comparison with inpatient care. *JACC Cardiovasc Imaging* 2011;4:862-70.
103. Miller CD, Hoekstra JW, Lefebvre C, et al. Provider-directed imaging stress testing reduces health care expenditures in lower-risk chest pain patients presenting to the emergency department. *Circ Cardiovasc Imaging* 2012;5:111-8.
104. Goldhaber SZ, Visani L, De Rosa M. Acute pulmonary embolism: clinical outcomes in the International Cooperative Pulmonary Embolism Registry (ICOPER). *Lancet* 1999;353:1386-9.
105. Office of the Surgeon General, National Heart, Lung, and Blood Institute. The surgeon general's call to action to prevent deep vein thrombosis and pulmonary embolism. Rockville, Maryland: Office of the Surgeon General; 2008.
106. Rodger M, Makropoulos D, Turek M, et al. Diagnostic value of the electrocardiogram in suspected pulmonary embolism. *Am J Cardiol* 2000;86:807-9.
107. Miniati M, Monti S, Pratali L, et al. Value of transthoracic echocardiography in the diagnosis of pulmonary embolism: results of a prospective study in unselected patients. *Am J Med* 2001;110:528-35.
108. McConnell MV, Solomon SD, Rayan ME, Come PC, Goldhaber SZ, Lee RT. Regional right ventricular dysfunction detected by echocardiography in acute pulmonary embolism. *Am J Cardiol* 1996;78:469-73.
109. Goldhaber SZ. Pulmonary embolism. *Lancet* 2004;363:1295-305.
110. Konstantinides S, Geibel A, Olschewski M, et al. Importance of cardiac troponins I and T in risk stratification of patients with acute pulmonary embolism. *Circulation* 2002;106:1263-8.
111. Westermarck N. On the roentgen diagnosis of lung embolism. *Acta Radiol* 1938;357-72.
112. Hampton AO, Castleman B. Correlation of postmortem chest tele-roentgenograms with autopsy findings with special reference to pulmonary embolism and infarction. *Am J Roentgenol Radium Ther Nucl Med* 1940:305-26.
113. Ceriani E, Combesure C, Le Gal G, et al. Clinical prediction rules for pulmonary embolism: a systematic review and meta-analysis. *J Thromb Haemost* 2010;8:957-70.
114. Wells PS, Ginsberg JS, Anderson DR, et al. Use of a clinical model for safe management of patients with suspected pulmonary embolism. *Ann Intern Med* 1998;129:997-1005.
115. Wells PS, Anderson DR, Rodger M, et al. Derivation of a simple clinical model to categorize patients probability of pulmonary embolism: increasing the models utility with the SimpliRED D-dimer. *Thromb Haemost* 2000;83:416-20.
116. Douma RA, Mos IC, Erkens PM, et al. Performance of 4 clinical decision rules in the diagnostic management of acute pulmonary embolism: a prospective cohort study. *Ann Intern Med* 2011;154:709-18.
117. Wicki J, Perneger TV, Junod AF, Bounameaux H, Perrier A. Assessing clinical probability of pulmonary embolism in the emergency ward: a simple score. *Arch Intern Med* 2001;161:92-7.
118. Righini M, Perrier A, De Moerloose P, Bounameaux H. D-Dimer for venous thromboembolism diagnosis: 20 years later. *J Thromb Haemost* 2008;6:1059-71.
119. Pollack CV, Schreiber D, Goldhaber SZ, et al. Clinical characteristics, management, and outcomes of patients diagnosed with acute pulmonary embolism in the emergency department: initial report of EMPEROR (Multicenter Emergency Medicine Pulmonary Embolism in the Real World Registry). *J Am Coll Cardiol* 2011;57:700-6.

120. Torbicki A, Perrier A, Konstantinides S, et al. Guidelines on the diagnosis and management of acute pulmonary embolism: the Task Force for the Diagnosis and Management of Acute Pulmonary Embolism of the European Society of Cardiology (ESC). *Eur Heart J* 2008;29:2276-315.
121. Coche E, Verschuren F, Keyeux A, et al. Diagnosis of acute pulmonary embolism in outpatients: comparison of thin-collimation multi-detector row spiral CT and planar ventilation-perfusion scintigraphy. *Radiology* 2003;229:757-65.
122. Gerard SK, Hsu TC. Pulmonary embolism: diagnosis with spiral CT versus ventilation-perfusion scintigraphy. *Radiology* 1999;210:576-7.
123. Katsouda E, Mystakidou K, Rapti A, et al. Evaluation of spiral computed tomography versus ventilation/perfusion scanning in patients clinically suspected of pulmonary embolism. *In Vivo* 2005;19:873-8.
124. Quinn MF, Lundell CJ, Klotz TA, et al. Reliability of selective pulmonary arteriography in the diagnosis of pulmonary embolism. *AJR Am J Roentgenol* 1987;149:469-71.
125. Hiorns MP, Mayo JR. Spiral computed tomography for acute pulmonary embolism. *Can Assoc Radiol J* 2002;53:258-68.
126. Mayo JR, Remy-Jardin M, Muller NL, et al. Pulmonary embolism: prospective comparison of spiral CT with ventilation-perfusion scintigraphy. *Radiology* 1997;205:447-52.
127. Bettmann MA, Baginski SG, White RD, et al. ACR Appropriateness Criteria[®] acute chest pain—suspected pulmonary embolism. *J Thorac Imaging* 2012;27:W28-31.
128. Klok FA, Mos IC, Kroft LJ, de Roos A, Huisman MV. Computed tomography pulmonary angiography as a single imaging test to rule out pulmonary embolism. *Curr Opin Pulmon Med* 2011;17:380-6.
129. Perrier A, Roy PM, Sanchez O, et al. Multidetector-row computed tomography in suspected pulmonary embolism. *N Engl J Med* 2005;352:1760-8.
130. Huisman MV, Klok FA. How I diagnose acute pulmonary embolism. *Blood* 2013;121:4443-8.
131. Hunsaker AR, Zou KH, Poh AC, et al. Routine pelvic and lower extremity CT venography in patients undergoing pulmonary CT angiography. *AJR Am J Roentgenol* 2008;190:322-6.
132. Carrier M, Righini M, Wells PS, et al. Subsegmental pulmonary embolism diagnosed by computed tomography: incidence and clinical implications. A systematic review and meta-analysis of the management outcome studies. *J Thromb Haemost* 2010;8:1716-22.
133. Lu MT, Demehri S, Cai T, et al. Axial and reformatted four-chamber right ventricle-to-left ventricle diameter ratios on pulmonary CT angiography as predictors of death after acute pulmonary embolism. *AJR Am J Roentgenol* 2012;198:1353-60.
134. Stein PD, Woodard PK, Weg JG, et al. Diagnostic pathways in acute pulmonary embolism: recommendations of the PIOPED II investigators. *Am J Med* 2006;119:1048-55.
135. Garcia-Bolado A, Del Cura JL. CT venography vs ultrasound in the diagnosis of thromboembolic disease in patients with clinical suspicion of pulmonary embolism. *Emerg Radiol* 2007;14:403-9.
136. Johnson JC, Brown MD, McCullough N, Smith S. CT lower extremity venography in suspected pulmonary embolism in the ED. *Emerg Radiol* 2006;12:160-3.
137. Value of the ventilation/perfusion scan in acute pulmonary embolism. Results of the prospective investigation of pulmonary embolism diagnosis (PIOPED). *JAMA* 1990;263:2753-9.
138. Kalb B, Sharma P, Tigges S, et al. MR imaging of pulmonary embolism: diagnostic accuracy of contrast-enhanced 3D MR pulmonary angiography, contrast-enhanced low-flip angle 3D GRE, and non-enhanced free-induction FISP sequences. *Radiology* 2012;263:271-8.
139. Schiebler ML, Nagle SK, Francois CJ, et al. Effectiveness of MR angiography for the primary diagnosis of acute pulmonary embolism: Clinical outcomes at 3 months and 1 year. *J Magn Reson Imaging* 2013;38:914-25.
140. van Beek EJ, Oudkerk M. MR imaging of pulmonary embolism. *Radiology* 2012;264:917.
141. 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;152:434-43.
142. Stein PD, Athanasoulis C, Alavi A, et al. Complications and validity of pulmonary angiography in acute pulmonary embolism. *Circulation* 1992;85:462-8.
143. Damodaram M, Kaladindi M, Luckit J, Yoong W. D-dimers as a screening test for venous thromboembolism in pregnancy: is it of any use? *J Obstet Gynaecol* 2009;29:101-3.
144. Chan WS, Chunilal S, Lee A, Crowther M, Rodger M, Ginsberg JS. A red blood cell agglutination D-dimer test to exclude deep venous thrombosis in pregnancy. *Ann Intern Med* 2007;147:165-70.
145. Chan WS, Lee A, Spencer FA, et al. D-dimer testing in pregnant patients: towards determining the next 'level' in the diagnosis of deep vein thrombosis. *J Thromb Haemost* 2010;8:1004-11.
146. Leung AN, Bull TM, Jaeschke R, et al. American Thoracic Society documents: an official American Thoracic Society/Society of Thoracic Radiology clinical practice guideline—evaluation of suspected pulmonary embolism in pregnancy. *Radiology* 2012;262:635-46.
147. Hagan PG, Nienaber CA, Isselbacher EM, et al. The International Registry of Acute Aortic Dissection (IRAD): new insights into an old disease. *JAMA* 2000;283:897-903.
148. Buckley O, Rybicki FJ, Gerson DS, et al. Imaging features of intramural hematoma of the aorta. *Int J Cardiovasc Imaging* 2010;26:65-76.
149. Suzuki T, Distant A, Zizza A, et al. Diagnosis of acute aortic dissection by D-dimer: the International Registry of Acute Aortic Dissection Substudy on Biomarkers (IRAD-Bio) experience. *Circulation* 2009;119:2702-7.
150. Hiratzka LF, Bakris GL, Beckman JA, et al. 2010 ACCF/AHA/AATS/ACR/ASA/SCA/SCAI/SIR/STS/SVM guidelines for the diagnosis and management of patients with thoracic aortic disease. A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines, American Association for Thoracic Surgery, American College of Radiology, American Stroke Association, Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, Society of Interventional Radiology, Society of Thoracic Surgeons, and Society for Vascular Medicine. *J Am Coll Cardiol* 2010;55:e27-129.
151. Alkadhi H, Wildermuth S, Desbiolles L, et al. Vascular emergencies of the thorax after blunt and iatrogenic trauma: multi-detector row CT and three-dimensional imaging. *Radiographics* 2004;24:1239-55.
152. Bhalla S, Menias CO, Heiken JP. CT of acute abdominal aortic disorders. *Radiol Clin North Am* 2003;41:1153-69.
153. Chiu KW, Lakshminarayan R, Ettles DF. Acute aortic syndrome: CT findings. *Clin Radiol* 2013;68:741-8.
154. Sommer T, Fehske W, Holzkecht N, et al. Aortic dissection: a comparative study of diagnosis with spiral CT, multiplanar transesophageal echocardiography, and MR imaging. *Radiology* 1996;199:347-52.
155. Loyv AJ, Rosenblum JK, Levsky JM, et al. Acute aortic syndromes: a second look at dual-phase CT. *AJR Am J Roentgenol* 2013;200:805-11.
156. Pepi M, Campodonico J, Galli C, et al. Rapid diagnosis and management of thoracic aortic dissection and intramural haematoma: a prospective study of advantages of multiplane vs. biplane transesophageal echocardiography. *Eur J Echocardiogr* 2000;1:72-9.
157. Willens HJ, Kessler KM. Transesophageal echocardiography in the diagnosis of diseases of the thoracic aorta: part 1. Aortic dissection, aortic intramural hematoma, and penetrating atherosclerotic ulcer of the aorta. *Chest* 1999;116:1772-9.
158. Arciniegas JG, Soto B, Little WC, Papapietro SE. Cineangiography in the diagnosis of aortic dissection. *Am J Cardiol* 1981;47:890-4.
159. Dinsmore RE, Willerson JT, Buckley MJ. Dissecting aneurysm of the aorta: aortographic features affecting prognosis. *Radiology* 1972;105:567-72.

160. Soto B, Harman MA, Ceballos R, Barcia A. Angiographic diagnosis of dissecting aneurysm of the aorta. *Am J Roentgenol Radium Ther Nucl Med* 1972;116:146-54.
161. Nordon I, Thompson M, Loftus I. Endovascular treatment of acute aortic dissection: indications, techniques and results. *J Cardiovasc Surg* 2012;53:43-51.
162. Ayaram D, Bellolio MF, Murad MH, et al. Triple rule-out computed tomographic angiography for chest pain: a diagnostic systematic review and meta-analysis. *Acad Emerg Med* 2013;20:861-71.
163. Rogers IS, Banerji D, Siegel EL, et al. Usefulness of comprehensive cardiothoracic computed tomography in the evaluation of acute undifferentiated chest discomfort in the emergency department (CAPTURE). *Am J Cardiol* 2011;107:643-50.
164. Schertler T, Frauenfelder T, Stolzmann P, et al. Triple rule-out CT in patients with suspicion of acute pulmonary embolism: findings and accuracy. *Acad Radiol* 2009;16:708-17.
165. White CS, Kuo D, Kelemen M, et al. Chest pain evaluation in the emergency department: can MDCT provide a comprehensive evaluation? *AJR Am J Roentgenol* 2005;185:533-40.
166. 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;248:438-46.
167. Rybicki FJ, Otero HJ, Steigner ML, et al. Initial evaluation of coronary images from 320-detector row computed tomography. *Int J Cardiovasc Imaging* 2008;24:535-46.
168. Achenbach S, Marwan M, Schepis T, et al. High-pitch spiral acquisition: a new scan mode for coronary CT angiography. *J Cardiovasc Comput Tomogr* 2009;3:117-21.
169. Litt H. Are three diagnoses always better than one? *Acad Radiol* 2009;16:1037-8.