### American College of Radiology ACR Appropriateness Criteria® Chest Pain-Possible Acute Coronary Syndrome

<u>Variant: 1</u> Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transthoracic stress	Usually Appropriate	0
Radiography chest	Usually Appropriate	<b>જ</b>
CTA coronary arteries with IV contrast	Usually Appropriate	<b>※ ※</b>
SPECT or SPECT/CT MPI rest and stress	Usually Appropriate	<b>※ ※ ※</b>
US echocardiography transthoracic resting	May Be Appropriate	0
MRI heart function and morphology without and with IV contrast	May Be Appropriate	0
MRI heart with function and inotropic stress without and with IV contrast	May Be Appropriate	0
MRI heart with function and inotropic stress without IV contrast	May Be Appropriate	0
MRI heart with function and vasodilator stress perfusion without and with IV contrast	May Be Appropriate	О
CT coronary calcium	May Be Appropriate	<b>∵ ∵</b>
CTA chest with IV contrast	May Be Appropriate	<b>※ ※</b>
SPECT or SPECT/CT MPI rest only	May Be Appropriate	<b>※ ※</b>
Rb-82 PET/CT MPI rest and stress	May Be Appropriate (Disagreement)	<b>⊗⊗⊗</b>
US echocardiography transesophageal	Usually Not Appropriate	0
Arteriography coronary	Usually Not Appropriate	<b>※ ※</b>
MRA coronary arteries without and with IV contrast	Usually Not Appropriate	0
MRA coronary arteries without IV contrast	Usually Not Appropriate	0
MRI heart function and morphology without IV contrast	Usually Not Appropriate	0
CT chest with IV contrast	Usually Not Appropriate	<b>∵</b>
CT chest without and with IV contrast	Usually Not Appropriate	<b>∵</b>
CT chest without IV contrast	Usually Not Appropriate	<b>※ ※</b>

### **Variant: 2** Chest pain, high probability for acute coronary syndrome. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
Radiography chest	Usually Appropriate	•
Arteriography coronary	Usually Appropriate	<b>∵</b>
US echocardiography transthoracic resting	May Be Appropriate	0
US echocardiography transthoracic stress	May Be Appropriate (Disagreement)	0
MRI heart function and morphology without and with IV contrast	May Be Appropriate (Disagreement)	0
CTA coronary arteries with IV contrast	May Be Appropriate	<b>⊗ ⊗ ⊗</b>
SPECT or SPECT/CT MPI rest only	May Be Appropriate (Disagreement)	<b>∵</b> •••

SPECT or SPECT/CT MPI rest and stress	May Be Appropriate	<b>※※</b>
US echocardiography transesophageal	Usually Not Appropriate	0
MRA coronary arteries without and with IV contrast	Usually Not Appropriate	0
MRA coronary arteries without IV contrast	Usually Not Appropriate	0
MRI heart function and morphology without IV contrast	Usually Not Appropriate	0
MRI heart with function and inotropic stress without and with IV contrast	Usually Not Appropriate	0
MRI heart with function and inotropic stress without IV contrast	Usually Not Appropriate	0
MRI heart with function and vasodilator stress perfusion without and with IV contrast	Usually Not Appropriate	0
CT chest with IV contrast	Usually Not Appropriate	<b>∵</b>
CT chest without and with IV contrast	Usually Not Appropriate	<b>∵</b>
CT chest without IV contrast	Usually Not Appropriate	<b>∵</b>
CT coronary calcium	Usually Not Appropriate	<b>∵</b>
CTA chest with IV contrast	Usually Not Appropriate	<b>∵</b>
Rb-82 PET/CT MPI rest and stress	Usually Not Appropriate	<b>※ ※ ※</b>

#### **Panel Members**

Juan C. Batlle, MD, MBA<sup>a</sup>; Jacobo Kirsch, MD, MBA<sup>b</sup>; Michael A. Bolen, MD<sup>c</sup>; W. Patricia Bandettini, MD<sup>d</sup>; Richard K. J. Brown, MD<sup>e</sup>; Christopher J. Francois, MD<sup>f</sup>; Mauricio S. Galizia, MD<sup>g</sup>; Kate Hanneman, MD, MPH<sup>h</sup>; Joao R. Inacio, MD<sup>i</sup>; Thomas V. Johnson, MD<sup>j</sup>; Faisal Khosa, MD, MBA<sup>k</sup>; Rajesh Krishnamurthy, MD<sup>l</sup>; Prabhakar Rajiah, MD<sup>m</sup>; Satinder P. Singh, MD<sup>n</sup>; Christian A. Tomaszewski, MD, MBA, MS<sup>o</sup>; Todd C. Villines, MD<sup>p</sup>; Samuel Wann, MD<sup>q</sup>; Phillip M. Young, MD<sup>r</sup>; Stefan L. Zimmerman, MD<sup>s</sup>; Suhny Abbara, MD.<sup>t</sup>

#### **Summary of Literature Review**

#### Introduction/Background

Cardiovascular disease is the leading cause of death in the United States. Annually, there are more than 8 million visits to emergency departments by patients with acute chest pain [1], with estimated health care costs of \$13 to \$15 billion [2]. Approximately 5% to 13% of those patients who present with acute chest pain are eventually found to have an acute coronary syndrome (ACS) [1]. ACS includes ST-segment elevation myocardial infarction (MI), non-ST-segment elevation (NSTE) MI, and unstable angina (acute ischemia without necrosis) [3]. Once diagnosed with ACS, the patient may be urgently transferred to a cardiac catheterization laboratory for invasive angiography and potential coronary revascularization [4,5]. For patients not identified immediately with ACS, categorizing low, intermediate, and high probability for ACS helps identify increasing risk for downstream major adverse cardiac events (MACE). Patients are predominantly stratified by clinical suspicion (including risk scores and risk stratification models), the evaluation of prompt electrocardiogram (ECG; serially if necessary), and the use of cardiac biomarkers (eg, serial troponins and B-type natriuretic peptide) [6,7]. Commonly used risk scores include the Thrombolysis in Myocardial Infarction risk score (TIMI RS), Global Registry of Acute Cardiac Events risk score (GRACE RS), the History, Electrocardiogram, Age, Risk factors, Troponin (HEART) score [8], and the Platelet glycoprotein IIb/IIIa in Unstable angina: Receptor Suppression Using Integrilin

Therapy risk score (PURSUIT RS), among many others [9,10]. Risk stratification of patients into low, intermediate, and high probability for ACS may therefore differ according to available institutional resources and practice, but these categories generally correspond to increasing likelihood of downstream MACE due to ACS. Historical risk scores such as the TIMI score, the GRACE score, and the PURSUIT score are being replaced by more accurate risk stratification tools such as the HEART score, which was designed specifically for evaluation of patients with chest pain in the emergency department without a diagnosis of ACS [8].

High-risk patients with a convincing clinical picture may quickly progress to an invasive strategy or to the presumption of obstructive coronary artery disease (CAD) treated medically. In the setting of confirmed ACS, "time is myocardium and time is outcomes," and prompt diagnosis can dramatically influence the downstream cardiovascular event rate [11-13]. However, ACS cannot be excluded in many patients with acute chest pain, even after initial clinical evaluation and diagnostic workup with ECG and cardiac biomarkers, and as many as 80% of these chest pain patients are admitted or observed for evaluation [14,15]. In the 1990s, studies showed 2% to 8% of emergency department patients were inappropriately discharged with a missed diagnosis of ACS, presenting a grave risk to those patients and the potential of litigation for physicians and healthcare facilities [16]. Although more recent studies have shown lower rates of missed diagnosis, appropriate identification of ACS remains an important issue.

Noninvasive imaging may therefore be indicated for risk stratification and clinical management in both low-risk and intermediate-risk patients [17]. This has continued to gain popularity since the first decade of the 2000s, with advanced medical imaging among chest pain patients quintupling [18]. This approach also serves to identify patients with a significant ischemic burden who could benefit from coronary revascularization [19-21]. Noninvasive imaging aids in the evaluation of the acute chest pain patients by either functionally determining a myocardial segment perfusion abnormality (eg, relative hypoperfusion, or a wall motion, or thickening abnormality, usually at stress testing) or anatomically visualizing an obstructive coronary artery stenosis. Although noninvasive imaging approaches have sensitivities and specificities in the 85% to 90% range, the corresponding false diagnosis rates are in the 10% to 15% range, and therefore consideration may be made to avoid diagnostic imaging altogether in patients at either end of the pretest probability spectrum [22]. Therefore, patient selection, as determined by clinical judgment and tools such as the HEART score, is critical because there has been historically a low yield of routine noninvasive cardiac imaging in low-risk patients [23-26].

Noncoronary etiologies for chest pain can also be established with imaging, the results of which may alter the patient's postdischarge care altogether. It is not uncommon for a patient to have acute chest pain occurring from other cardiovascular causes or noncardiac etiologies [17,27,28].

The available noninvasive cardiac imaging modalities include chest radiographs, rest single-photon emission computed tomography (SPECT) myocardial perfusion imaging (MPI), stress SPECT MPI, echocardiography (transthoracic and transesophageal), multidetector CT, PET (metabolic and perfusion), and MRI.

#### **Special Imaging Considerations**

For the purposes of distinguishing between CT and CT angiography (CTA), the ACR Appropriateness Criteria topics use the definition in the <u>ACR-NASCI-SIR-SPR Practice Parameter</u>

#### for the Performance and Interpretation of Body Computed Tomography Angiography (CTA) [29]:

"CTA uses a thin-section CT acquisition that is timed to coincide with peak arterial or venous enhancement. The resultant volumetric dataset is interpreted using primary transverse reconstructions as well as multiplanar reformations and 3-D renderings."

All procedure elements are essential: 1) timing, 2) recons/reformats, and 3) 3-D renderings. Standard CTs with contrast also include timing issues and recons/reformats. Only in CTA; however, is 3-D rendering a **required** element. This corresponds to the definitions that CMS has applied to the CPT codes.

### **Discussion of Procedures by Variant**

Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

### A. Arteriography Coronary

In patients with low to intermediate risk, arteriography is not the first-line evaluation or management. Patients with a nondiagnostic ECG and negative cardiac biomarkers should follow a clinical pathway beginning with a noninvasive approach [30].

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

### **B. Radiography Chest**

Chest radiography is primarily used for ruling out conditions that may masquerade as acute myocardial ischemia, as well as defining secondary findings that may accompany acute MI. Acute pulmonary edema can be seen on chest radiographs without enlargement of the cardiac silhouette in patients with acute MI and no prior history of ischemic damage or associated mitral valve disease. Although chest radiography is insufficient to confirm or exclude the presence of significant CAD, it may be useful in demonstrating clinically important pathology in a significant minority of ACS-suspected patients [31]. Other cardiovascular entities, such as aortic aneurysms, aortic dissections, and pulmonary embolism, may be suggested from the chest radiograph but with far lower sensitivity than in other imaging modalities, such as multidetector CT. Noncardiac findings associated with chest pain that can be identified on chest radiography include pneumothorax, fractured ribs, pleural effusions, and pneumonia, among others.

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

### C. SPECT or SPECT/CT MPI Rest Only

SPECT perfusion scintigraphy is an important test in the assessment for myocardial ischemia. In patients with active chest pain, an ECG with no ischemic changes, and an initial negative troponin, a promptly read rest SPECT has been demonstrated to be safe and clinically effective [32,33]. Restonly MPI has been shown to be less sensitive than stress SPECT imaging if performed after the chest pain has subsided. The commonly used radionuclide agents are Tc-99m—labeled agents (eg, sestamibi, tetrofosmin). There is abundant literature describing the use of SPECT in ACS. The absence of a perfusion defect on an acute rest study is associated with a very high negative

predictive value for ACS evaluation. As such, rest alone nuclear MPI has an American College of Cardiology/American Heart Association class I, level A recommendation for evaluation of suspected ACS [34] and has a well-established, well-supported track record in evaluating acute chest pain patients [35,36].

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### D. SPECT or SPECT/CT MPI Rest and Stress

SPECT perfusion scintigraphy is an important test in the assessment for myocardial ischemia. Restonly MPI has been shown to be less sensitive than stress SPECT imaging if performed after the chest pain has subsided. The commonly used radionuclide agents are TI-201 (thallium) chloride and Tc-99m—labeled agents (eg, sestamibi, tetrofosmin). There is abundant literature describing the use of SPECT in ACS. A perfusion defect that becomes apparent or becomes larger during exercise stress or pharmacologic stress suggests ischemic myocardium. Patients with negative stress nuclear MPI can be safely discharged, and those with positive stress nuclear MPI have a higher likelihood of obstructive disease on subsequent coronary angiography compared with those evaluated by stress ECG [37]. In addition, trials in patients with stable ischemic heart disease suggest that the degree of ischemic myocardium may be more important than the presence of anatomic stenosis alone, using, for example, a threshold of 10% ischemic myocardium to identify patients likely to benefit from revascularization [38,39]. As such, vasodilator stress nuclear MPI has an American College of Cardiology/American Heart Association class I, level B recommendation for evaluation of suspected ACS [34] and has a well-established, well-supported track record in evaluating acute chest pain patients [35,36].

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

### **E. US Echocardiography Transthoracic Stress**

Stress echocardiography has been shown to be a modality equivalent to stress SPECT MPI in the acute setting in low- to intermediate-risk patients, with either exercise or a stress pharmacologic agent (such as dobutamine) inducing focal wall-motion abnormalities in the region(s) of ischemia [40-42]. When compared with stress ECG, stress echocardiography of acute chest pain patients in the emergency department has been shown to lead to fewer late events, including rehospitalization and late percutaneous coronary intervention [43,44], as well as excellent accuracy in predicting obstructive CAD on coronary angiography or subsequent cardiovascular events [45]. Positive stress echocardiography has been shown to identify incrementally more patients requiring revascularization in patients suspected of ACS when compared with a standard of care without use of imaging [46,47].

## Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

### F. US Echocardiography Transthoracic Resting

Conventional resting echocardiography in the emergency department has some limited benefit for detection of ischemic myocardium with abnormal wall motion and thereby risk stratification of suspected ACS patients [48,49]; however, it is more widely used for the evaluation of heart failure, valvular dysfunction, and pericardial effusion [41]. Advances in contrast echocardiography to evaluate ischemic changes in wall thickening [50-53] and strain echocardiography to evaluate abnormal myocardial deformation [54-57] may provide an expanded role for resting echocardiography in the evaluation of ACS, particularly in patients with active chest pain at the

time of imaging.

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### G. US Echocardiography Transesophageal

The primary usefulness of resting transesophageal echocardiography (TEE) in the setting of acute chest pain is in ruling out aortic dissection in unstable patients. TEE is also used to further define valvular dysfunction or intracardiac thrombus, which can be sequelae of ischemic events in the subacute setting. Because of the semi-invasive nature of TEE and because there is limited information that can be added in the setting of acute chest pain, this modality is generally not indicated in the workup of patients with acute chest pain [58].

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### **H. CTA Coronary Arteries**

In stable patients with suggested ACS at low or intermediate risk of adverse events, a noninvasive coronary imaging test (ie, coronary CTA [CCTA]) is a proven alternative to stress testing or selective coronary angiography [19,59,60]. CCTA has a very high negative predictive value for the detection of coronary atherosclerosis with or without significant stenosis and is an alternative to stress imaging in the emergency department and inpatient settings in patients at low to intermediate risk for CAD [59,61-64]. Large randomized controlled trials (eg, CT-STAT, ROMICAT I and II, ACRIN-PA, PROSPECT, CT-COMPARE, CATCH, and CATCH-2) have amply established the high negative predictive value (eg, safe discharge) and good prognosis of a negative CCTA in low- to intermediate-risk patients suspected of ACS when compared with standard pathways that predominantly involve stress nuclear MPI [65-72]. Normal CCTA has been shown to allow safe discharge from the emergency department without further workup, in both academic and community settings, with a negative predictive value for ACS over 95% [1,73-75], with equal or superior diagnostic performance when compared with stress echocardiography or nuclear MPI [76]. High-sensitivity troponin use has increased in Europe and in the United States to stratify patients with suspected ACS [77], but a CCTA strategy has still been found to be useful to avoid unnecessary downstream testing even when patients were first stratified by high-sensitivity troponin [78-80]. In a large multicenter study comparing CCTA with multiple other modalities used for ACS (stress cardiac MR [CMR], stress echocardiography, stress nuclear MPI, and stress PET), CCTA was found to have the highest diagnostic accuracy in finding patients with a significant coronary artery stenosis [81].

Novel applications of CT technology include stress CT perfusion imaging and CT–fractional flow reserve (FFR), both of which have well-established research support and are beginning to supplement anatomic CCTA information in daily clinical practice at certain centers. Stress CT perfusion imaging allows functional assessment of myocardial segments and has been shown to have similar diagnostic performance and predictive values when compared with stress MPI [82-85]. Although stress CT perfusion represents the typical approach to CT diagnosis of inducible ischemia, resting CT perfusion interpretation of myocardial segments from a routine resting CCTA has also shown utility in the diagnosis of ACS [86,87]. FFR is an invasively derived ratio comparing flow at hyperemia proximal and distal with a stenosis at catheterization, with powerful discriminatory value in determining the hemodynamic significance of the stenosis. CT-FFR uses computational fluid dynamic modeling techniques and/or machine learning to simulate the FFR process, using resting CCTA data and yield a CT-FFR number shown to correlate reasonably well

with catheter-derived FFR values and deliver equivalent clinical outcomes when using a CT-FFR-guided management pathway [88-92]. Research into the additive value of CT perfusion and CT-FFR is ongoing, particularly in chest pain patients presenting acutely to the emergency department rather than as stable outpatients [93].

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

### I. CT Coronary Calcium

The role of the calcium score as a standalone test in the acute setting has not been established [94]. Limited studies have been performed demonstrating that the absence of coronary artery calcium (CAC) has a high negative predictive value for ACS among lower-risk patients with chest pain [95]. Several studies have suggested that in young patients with chest pain, a calcium score of zero is not a reliable test to exclude CAD, and adverse events have been shown to occur in up to 6% of acute chest pain patients without coronary artery calcium [96]. The ability of a zero calcium score to allow safe discharge of low-risk acute chest pain patients continues to be actively studied [97-100].

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### J. CT Chest

Nongated chest CT, although useful for evaluating noncardiac thoracic pathology, does not currently have a role in the evaluation of possible ACS, although perfusion defects can be seen on contrast-enhanced nongated chest CT in patients with ACS [101,102].

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### **K. CTA Chest**

CTA of the chest has a well-established role for evaluating other etiologies that may mimic ACS, such as aortic dissection, acute pericarditis, pneumonia, and pneumothorax [27,103]. Nongated chest CTA intended to evaluate a patient for aortic dissection or pulmonary embolism may depict incidental coronary artery pathology, such as anomalous coronary arteries, obstructive CAD, and involvement of the coronary arteries by aortic dissection [104]. In particular, CTA for aortic dissection or pulmonary embolism may be performed with ECG-gating without specific intent to evaluate the coronary arteries (ie, gating intended to reduce pulsation artifact in the great vessels but the examination not otherwise tailored to the coronary arteries), and in those cases, coronary abnormalities may be even more readily apparent as an unexpected finding. Therefore, there is insufficient evidence to support nongated (or incidentally gated) CTA for the evaluation of ACS.

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### L. Rb-82 PET/CT Heart

A stress PET examination can reliably demonstrate myocardial blood flow using rubidium-82 (Rb-82) or nitrogen-13 (N-13) ammonia. Limited data are available for PET perfusion studies in the setting of acute chest pain, although there is growing evidence for diagnostic and prognostic applications in chronic coronary disease [105,106]. PET can also document anaerobic metabolism using fluorine-18-2-fluoro-2-deoxy-D-glucose and other metabolic tracers. This technology is less well studied in the workup of the acute chest pain patient but may have a role when combined with CTA [105,107,108]. Meta-analysis has shown PET to demonstrate excellent diagnostic performance when compared with other methods of evaluating ischemic myocardium [109].

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### M. MRI Heart with Function and Inotropic Stress

Although early ACS approaches of CMR included high-risk patients and tended to use rest-only CMR, more recent studies have demonstrated high negative predictive value and excellent diagnostic performance in a low- to intermediate-risk cohort when compared with nuclear MPI or stress echocardiography [110,111]. Multiple studies have shown that a vasodilator stress CMR strategy for chest pain patients can allow safe discharge and show similar clinical performance to other stress perfusion techniques [45,112-114]. However, inotropic stress agents like dobutamine, although useful for the characterization of stable ischemic heart disease [115,116], are relatively contraindicated in patients with recent or active chest pain, and so limited literature exists on the use of inotropic stress MRI for the evaluation of ACS.

# Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### N. MRI Heart with Function and Vasodilator Stress Perfusion

Although early ACS approaches of CMR included high-risk patients and tended to use rest-only CMR, more recent studies have demonstrated high negative predictive value and excellent diagnostic performance in a low- to intermediate-risk cohort when compared with nuclear MPI or stress echocardiography [110,111]. Multiple studies have shown that a stress CMR strategy for chest pain patients can allow safe discharge and show similar clinical performance to other stress-perfusion techniques [45,112-114]. In particular, CMR has been shown to have similar or better performance to nuclear MPI in determining the degree of ischemic myocardium, which may be an important predictor of outcomes after revascularization [117,118]. For example, several studies on outpatients with suspected CAD (eg, MR-IMPACT, CE-MARC, MR-INFORM) demonstrated superior performance of stress CMR when compared with nuclear SPECT MPI [119,120] and have recently reported noninferiority when compared with invasive FFR [121].

### Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### O. MRI Heart Function and Morphology

CMR with delayed postcontrast imaging and edema-weighted imaging provides assessment of the size, distribution, and transmural extent of acute or remote MI. Cine CMR has usefulness in demonstrating wall-motion abnormalities, which may accompany acute or chronic ischemic heart disease, and first-pass contrast-enhanced perfusion CMR can demonstrate myocardial perfusion abnormalities [110,111,122-124]. The use of T2-weighted CMR to identify myocardial edema can help predict outcomes in patients with NSTE-ACS without affecting time to catheterization [125]. In addition, CMR has a role in elucidating the cause of myocardial necrosis in patients with elevated cardiac biomarkers presumed to have ACS but with nonobstructive coronary arteries by CT or catheter angiography [126,127]. MRI, like CT, can also identify noncardiac reasons for chest pain. Both contrast-enhanced and nonenhanced time-of-flight angiographic techniques can be used for aortic pathology, and CMR can be used for the evaluation of other mimics of ACS with troponin elevation, including pericarditis, myocarditis, and Takotsubo cardiomyopathy [128,129]. New techniques in CMR, for example, myocardial mapping, may provide additional methods that can be used to evaluate patients with acute chest pain [130,131].

## Variant 1: Chest pain, low to intermediate probability for acute coronary syndrome. Initial imaging.

#### P. MRA Coronary Arteries

Although coronary MR angiography (MRA) has not been established in general practice, both angiographic and phase-contrast flow continue to be developed for coronary artery assessment in research centers [132]. Noncontrast angiographic whole-heart acquisition with 3-D steady-state free precession MRI technique can provide imaging of the coronary arteries and is particularly useful in the evaluation of coronary anomalies, bypass graft assessment, and coronary aneurysm formation [133]. Trials have demonstrated high sensitivity and moderate specificity of coronary MRA for the evaluation of obstructive coronary artery stenosis, particularly when used in combination with nonangiographic CMR sequences [119,134]. Future avenues of clinical use include reliable evaluation of coronary artery stenosis and characterization of plaque composition for the identification of vulnerable or high-risk plaques [135].

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. A. Arteriography Coronary

Prompt coronary angiography is the mainstay of diagnosis and management of patients at high risk for ACS, in particular those with an ischemic pattern on ECG [7]. By American College of Cardiology/American Heart Association guidelines, there is a class I, level A recommendation to direct ST-segment elevation patients suspected of ACS to the catheterization laboratory with a "door-to-device" time of ≤90 min [136-138]. The emphasis of timeliness in arteriography and reperfusion of the coronary arteries for ECG-positive ACS is such that the use of other modalities in the evaluation of high-risk ACS patients, particularly modalities with a significant time penalty (eg, MRI, PET, MPI), is limited.

In patients without ST-segment elevation, positive cardiac biomarkers may nonetheless suggest myocardial necrosis, and the ECG may demonstrate a NSTE ischemic pattern, including ST depression, transient ST-segment elevation, or prominent T-wave inversions [139]. ACS patients with unstable angina may have similar ECG patterns but demonstrate no biomarker evidence of myocardial necrosis (eg, troponin level within normal limits), though biomarker negativity in these patients may grow rarer as high-sensitivity biomarker tests become more widely available [140]. Patients with NSTE-ACS do not require immediate emergent evaluation in the catheterization laboratory in the absence of shock or medically refractory symptoms but are admitted for inpatient stabilization, relief of ischemic symptoms, and guideline-directed medical therapy. NSTE-ACS patients may then be managed with an ischemia-guided strategy (ie, only proceed to catheterization if ischemic signs or symptoms persist despite aggressive medical therapy) or an invasive strategy (ie, routine catheterization with the goal of revascularization, either as an early invasive strategy within 24 h or a delayed invasive strategy in the 24–72 h time frame) [139,141-143]. The optimal timing and choice of invasive angiography in patients with ST-segment or non-ST-segment ACS continues to be an active area of research.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. B. Radiography Chest

Chest radiography is primarily used for ruling out conditions that may masquerade as acute myocardial ischemia as well as defining secondary findings that may accompany acute MI. Acute pulmonary edema can be seen on chest radiographs without enlargement of the cardiac silhouette in patients with acute MI and no prior history of ischemic damage or associated mitral valve disease. Although chest radiography is insufficient to confirm or exclude the presence of significant

CAD, it may be useful in demonstrating clinically important pathology in a significant minority of ACS-suspected patients [31]. Other cardiovascular entities, such as aortic aneurysms, aortic dissections, and pulmonary embolism, may be suggested from the chest radiography but with far lower sensitivity than other imaging modalities such as multidetector CT. Noncardiac findings associated with chest pain that can be identified on the chest radiograph include pneumothorax, fractured ribs, pleural effusions, and pneumonia, among others.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. C. CTA Coronary Arteries

There is no relevant literature regarding the use of CCTA in the evaluation of ACS in high-probability patients.

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. D. CT Chest

Nongated chest CT, although useful for evaluating noncardiac thoracic pathology, does not currently have a role in the evaluation of possible ACS, although perfusion defects can be seen on nongated chest CT in patients with ACS [101,102]

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. E. CTA Chest

CTA of the chest has a well-established role for evaluating other etiologies that may mimic ACS, such as aortic dissection, acute pericarditis, pneumonia, and pneumothorax [27,103].

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. F. CT Coronary Calcium

There is no relevant literature regarding the use of CT calcium scoring in the evaluation of ACS in high-probability patients.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. G. MRA Coronary Arteries

There is no relevant literature regarding the use of coronary MRA in the evaluation of ACS in high-risk patients.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. H. MRI Heart Function and Morphology

The use of T2-weighted CMR to identify myocardial edema can help predict outcomes in patients with NSTE-ACS, without impacting time to catheterization, and a combination of noncontrast and postcontrast resting CMR sequences can help inform prognosis and identify myocardial areas at risk [125,144]. In addition, CMR has a role in elucidating the cause of myocardial necrosis in patients with elevated cardiac biomarkers presumed to have ACS but with nonobstructive coronary arteries by CT or catheter angiography [126-128,145].

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. I. MRI Heart with Function and Inotropic Stress

There is no relevant literature regarding the use of stress CMR in the evaluation of ACS in high-probability patients.

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. J. MRI Heart with Function and Vasodilator Stress Perfusion

There is no relevant literature regarding the use of stress perfusion CMR in the evaluation of ACS

in high-probability patients.

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. K. Rb-82 PET/CT Heart

There is no relevant literature regarding the use of stress PET/CT in the evaluation of ACS in high-probability patients.

### Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. L. SPECT or SPECT/CT MPI Rest Only

There is no relevant literature regarding the use of rest-only MPI in the evaluation of ACS in high-probability patients.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. M. SPECT or SPECT/CT MPI Rest and Stress

Noninvasive stress testing with nuclear SPECT-MPI may be helpful in NSTE-ACS patients for risk stratification before discharge in patients with an ischemia-guided strategy. High NSTE-ACS patients (eg, patients with left main disease, age >70, multivessel disease, diabetes mellitus, prior MI or revascularization, or depressed left ventricular function) may benefit from routine revascularization, but low-to intermediate-risk NSTE-ACS patients may receive less benefit from routine revascularization and therefore may benefit from risk stratification according to provocative testing with stress. In particular, nuclear MPI with stress can be used to identify low-risk patients suitable for early discharge [146,147].

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. N. US Echocardiography Transthoracic Stress

There is no relevant literature regarding the use of stress echocardiography in the evaluation of ACS in high-probability patients.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. O. US Echocardiography Transthoracic Rest

Conventional resting echocardiography in the emergency department has some limited benefit for detection of ischemic myocardium with abnormal wall motion and thereby risk stratification of suspected ACS patients [48,49]; however, it is more widely used for the evaluation of heart failure, valvular dysfunction, and pericardial effusion [41]. Assessment of left ventricle function is necessary in patients with confirmed ACS in order to guide pharmacological therapies and help determine revascularization choices (eg, percutaneous coronary intervention versus bypass graft surgery). Advances in contrast echocardiography to evaluate ischemic changes in wall thickening [50-53] and strain echocardiography to evaluate abnormal myocardial deformation [54-57] may provide a new role for resting echocardiography in the evaluation of ACS.

# Variant 2: Chest pain, high probability for acute coronary syndrome. Initial imaging. P. US Echocardiography Transesophageal

The primary usefulness of TEE in the setting of acute chest pain is in ruling out aortic dissection in unstable patients. TEE is also used to further define valvular dysfunction or intracardiac thrombus, which can be sequelae of ischemic events in the subacute setting. Because of the semi-invasive nature of TEE and because there is limited information that can be added in the setting of acute chest pain, this modality is generally not indicated in the workup of patients with acute chest pain [58].

#### **Summary of Recommendations**

- Variant 1: CTA coronary arteries with IV contrast, Tc-99m SPECT or SPECT/CT MPI rest and stress, or ultrasound echocardiography transthoracic stress is usually appropriate for the initial imaging of chest pain in adults with low to intermediate probability for ACS. These procedures are equivalent alternatives (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care). Radiography chest is a complementary procedure used for rapid triage in chest pain patients who may then benefit from more definitive imaging with regard to ACS. The panel did not agree on recommending Rb-82 PET/CT heart for the initial imaging of chest pain in adults with low to intermediate probability for ACS. There is insufficient medical literature to conclude whether or not these patients would benefit from Rb-82 PET/CT heart for this clinical scenario. Rb-82 PET/CT heart in this patient population is controversial but may be appropriate.
- Variant 2: Arteriography coronary is usually appropriate for the initial imaging of chest pain in adults with high probability for ACS. Radiography chest is a complementary procedure used for rapid triage in chest pain patients who may then benefit from more definitive imaging with regard to ACS. The panel did not agree on recommending MRI heart function and morphology without and with IV contrast or SPECT or SPECT/CT MPI rest only or ultrasound echocardiography transthoracic stress for the initial imaging of chest pain with high probability for ACS. There is insufficient medical literature to conclude whether or not these patients would benefit from these examinations for this clinical scenario. MRI heart function and morphology without and with IV contrast or SPECT or SPECT/CT MPI rest only or ultrasound echocardiography transthoracic stress in this patient population is controversial but may be appropriate.

### **Supporting Documents**

The evidence table, literature search, and appendix for this topic are available at <a href="https://acsearch.acr.org/list">https://acsearch.acr.org/list</a>. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at <a href="https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria">https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria</a>.

#### **Appropriateness Category Names and Definitions**

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate		The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable riskbenefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate	5	The individual ratings are too dispersed from the

(Disagreement)		panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

#### **Relative Radiation Level Information**

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria Radiation Dose Assessment Introduction document.

#### **Relative Radiation Level Designations**

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
0	0 mSv	0 mSv
	<0.1 mSv	<0.03 mSv
<b>*</b>	0.1-1 mSv	0.03-0.3 mSv
	1-10 mSv	0.3-3 mSv
	10-30 mSv	3-10 mSv
$\mathbf{ \odot \odot \odot \odot \odot }$	30-100 mSv	10-30 mSv

<sup>\*</sup>RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

#### References

- **1.** Raff GL, Hoffmann U, Udelson JE. Trials of Imaging Use in the Emergency Department for Acute Chest Pain. [Review]. Jacc: Cardiovascular Imaging. 10(3):338-349, 2017 Mar.
- 2. Maffei E, Seitun S, Guaricci AI, Cademartiri F. Chest pain: coronary CT in the ER. [Review]. British Journal of Radiology. 89(1061):20150954, 2016.Br J Radiol. 89(1061):20150954, 2016.
- 3. Cannon CP, Battler A, Brindis RG, et al. American College of Cardiology key data elements and definitions for measuring the clinical management and outcomes of patients with acute coronary syndromes. A report of the American College of Cardiology Task Force on Clinical Data Standards (Acute Coronary Syndromes Writing Committee). J Am Coll Cardiol. 2001; 38(7):2114-2130.

- 4. Antman EM, Hand M, Armstrong PW, et al. 2007 Focused Update of the ACC/AHA 2004 Guidelines for the Management of Patients With ST-Elevation Myocardial Infarction: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines: developed in collaboration With the Canadian Cardiovascular Society endorsed by the American Academy of Family Physicians: 2007 Writing Group to Review New Evidence and Update the ACC/AHA 2004 Guidelines for the Management of Patients With ST-Elevation Myocardial Infarction, Writing on Behalf of the 2004 Writing Committee. Circulation. 2008; 117(2):296-329.
- 5. Nallamothu BK, Bates ER, Herrin J, Wang Y, Bradley EH, Krumholz HM. Times to treatment in transfer patients undergoing primary percutaneous coronary intervention in the United States: National Registry of Myocardial Infarction (NRMI)-3/4 analysis. Circulation. 2005; 111(6):761-767.
- **6.** Haaf P, Reichlin T, Corson N, et al. B-type natriuretic peptide in the early diagnosis and risk stratification of acute chest pain. Am J Med. 124(5):444-52, 2011 May.
- **7.** Thygesen K, Alpert JS, Jaffe AS, et al. Third universal definition of myocardial infarction. Circulation. 126(16):2020-35, 2012 Oct 16.
- **8.** Six AJ, Backus BE, Kelder JC. Chest pain in the emergency room: value of the HEART score. Neth Heart J 2008;16:191-6.
- **9.** de Araujo Goncalves P, Ferreira J, Aguiar C, Seabra-Gomes R. TIMI, PURSUIT, and GRACE risk scores: sustained prognostic value and interaction with revascularization in NSTE-ACS. Eur Heart J. 26(9):865-72, 2005 May.
- **10.** Yan AT, Yan RT, Tan M, et al. Risk scores for risk stratification in acute coronary syndromes: useful but simpler is not necessarily better. Eur Heart J. 28(9):1072-8, 2007 May.
- **11.** Fu Y, Goodman S, Chang WC, Van De Werf F, Granger CB, Armstrong PW. Time to treatment influences the impact of ST-segment resolution on one-year prognosis: insights from the assessment of the safety and efficacy of a new thrombolytic (ASSENT-2) trial. Circulation. 104(22):2653-9, 2001 Nov 27.
- **12.** Gibson CM.. Time is myocardium and time is outcomes. Circulation. 104(22):2632-4, 2001 Nov 27.
- 13. Levine GN, Bates ER, Blankenship JC, et al. 2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions.[Erratum appears in Circulation. 2012 Feb 28;125(8):e412 Note: Dosage error in article text]. Circulation. 124(23):e574-651, 2011 Dec 06.
- **14.** Pernes JM, Dupouy P, Labbe R, et al. Management of acute chest pain: A major role for coronary CT angiography. [Review]. Diagn Interv Imaging. 96(11):1105-12, 2015 Nov.
- **15.** Welch RD, Zalenski RJ, Frederick PD, et al. Prognostic value of a normal or nonspecific initial electrocardiogram in acute myocardial infarction. JAMA. 286(16):1977-84, 2001 Oct 24-31.
- **16.** Pope JH, Aufderheide TP, Ruthazer R, et al. Missed diagnoses of acute cardiac ischemia in the emergency department. N Engl J Med. 342(16):1163-70, 2000 Apr 20.

- **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(17):1756-1776.
- **18.** Bhuiya FA, Pitts SR, McCaig LF. Emergency department visits for chest pain and abdominal pain: United States, 1999-2008. NCHS data brief. (43)1-8, 2010 Sep.
- 19. Anderson JL, Adams CD, Antman EM, et al. ACC/AHA 2007 guidelines for the management of patients with unstable angina/non-ST-Elevation myocardial infarction: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to Revise the 2002 Guidelines for the Management of Patients With Unstable Angina/Non-ST-Elevation Myocardial Infarction) developed in collaboration with the American College of Emergency Physicians, the Society for Cardiovascular Angiography and Interventions, and the Society of Thoracic Surgeons endorsed by the American Association of Cardiovascular and Pulmonary Rehabilitation and the Society for Academic Emergency Medicine. J Am Coll Cardiol. 2007; 50(7):e1-e157.
- **20.** 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(11):1095-1104.
- **21.** Mehta SR, Cannon CP, Fox KA, et al. Routine vs selective invasive strategies in patients with acute coronary syndromes: a collaborative meta-analysis of randomized trials. JAMA. 2005; 293(23):2908-2917.
- **22.** Task Force Members, Montalescot G, Sechtem U, et al. 2013 ESC guidelines on the management of stable coronary artery disease: the Task Force on the management of stable coronary artery disease of the European Society of Cardiology.[Erratum appears in Eur Heart J. 2014 Sep 1;35(33):2260-1]. Eur Heart J. 34(38):2949-3003, 2013 Oct.
- **23.** Borges Santos M, Ferreira AM, de Araujo Goncalves P, et al. Diagnostic yield of current referral strategies for elective coronary angiography in suspected coronary artery disease-an analysis of the ACROSS registry. Rev Port Cardiol. 32(6):483-8, 2013 Jun.
- **24.** Cremer PC, Khalaf S, Agarwal S, et al. Myocardial perfusion imaging in emergency department patients with negative cardiac biomarkers: yield for detecting ischemia, short-term events, and impact of downstream revascularization on mortality. Circ Cardiovasc Imaging. 7(6):912-9, 2014 Nov.
- **25.** Hartsell S, Dorais J, Preston R, et al. False-positive rates of provocative cardiac testing in chest pain patients admitted to an emergency department observation unit. Crit. pathw. cardiol.. 13(3):104-8, 2014 Sep.
- **26.** Patel MR, Peterson ED, Dai D, et al. Low diagnostic yield of elective coronary angiography. N Engl J Med. 2010;362(10):886-895.
- **27.** Rubinshtein R, Halon DA, Gaspar T, et al. Impact of 64-slice cardiac computed tomographic angiography on clinical decision-making in emergency department patients with chest pain of possible myocardial ischemic origin. Am J Cardiol. 2007; 100(10):1522-1526.
- **28.** Solinas L, Raucci R, Terrazzino S, et al. Prevalence, clinical characteristics, resource utilization and outcome of patients with acute chest pain in the emergency department. A multicenter, prospective, observational study in north-eastern Italy. Ital Heart J. 2003; 4(5):318-324.
- **29.** American College of Radiology. ACR–NASCI–SIR–SPR Practice Parameter for the

- Performance and Interpretation of Body Computed Tomography Angiography (CTA). Available at: https://gravitas.acr.org/PPTS/GetDocumentView?docId=164+&releaseId=2.
- 30. Emergency Department Patients With Chest Pain Writing Panel, Rybicki FJ, Udelson JE, et al. 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, J. Am. Coll. Radiol., 13(2):e1-e29, 2016 Feb.
- **31.** Goldschlager R, Roth H, Solomon J, et al. Validation of a clinical decision rule: chest X-ray in patients with chest pain and possible acute coronary syndrome. EMERG. RADIOL.. 21(4):367-72, 2014 Aug.
- **32.** Kontos MC, Fratkin MJ, Jesse RL, Anderson FP, Ornato JP, Tatum JL. Sensitivity of acute rest myocardial perfusion imaging for identifying patients with myocardial infarction based on a troponin definition. J Nucl Cardiol. 2004; 11(1):12-19.
- **33.** Udelson JE, Beshansky JR, Ballin DS, et al. Myocardial perfusion imaging for evaluation and triage of patients with suspected acute cardiac ischemia: a randomized controlled trial. JAMA. 2002;288(21):2693-2700.
- **34.** Klocke FJ, Baird MG, Lorell BH, et al. ACC/AHA/ASNC guidelines for the clinical use of cardiac radionuclide imaging--executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASNC Committee to Revise the 1995 Guidelines for the Clinical Use of Cardiac Radionuclide Imaging). J Am Coll Cardiol. 42(7):1318-33, 2003 Oct 01.
- **35.** Dedic A, Genders TS, Nieman K, Hunink MG. Imaging strategies for acute chest pain in the emergency department. [Review]. AJR Am J Roentgenol. 200(1):W26-38, 2013 Jan.
- **36.** Ghatak A, Hendel RC. Role of imaging for acute chest pain syndromes. [Review]. Semin Nucl Med. 43(2):71-81, 2013 Mar.
- **37.** Lim SH, Anantharaman V, Sundram F, et al. Stress myocardial perfusion imaging for the evaluation and triage of chest pain in the emergency department: a randomized controlled trial. J Nucl Cardiol. 20(6):1002-12, 2013 Dec.
- **38.** Hachamovitch R, Rozanski A, Shaw LJ, et al. Impact of ischaemia and scar on the therapeutic benefit derived from myocardial revascularization vs. medical therapy among patients undergoing stress-rest myocardial perfusion scintigraphy. Eur Heart J. 32(8):1012-24, 2011 Apr.
- **39.** Shaw LJ, Weintraub WS, Maron DJ, et al. Baseline stress myocardial perfusion imaging results and outcomes in patients with stable ischemic heart disease randomized to optimal medical therapy with or without percutaneous coronary intervention. Am Heart J. 164(2):243-50, 2012 Aug.
- **40.** Davies R, Liu G, Sciamanna C, Davidson WR Jr, Leslie DL, Foy AJ. Comparison of the Effectiveness of Stress Echocardiography Versus Myocardial Perfusion Imaging in Patients Presenting to the Emergency Department With Low-Risk Chest Pain. American Journal of Cardiology. 118(12):1786-1791, 2016 Dec 15.Am J Cardiol. 118(12):1786-1791, 2016 Dec 15.

- **41.** Lancellotti P, Price S, Edvardsen T, et al. The use of echocardiography in acute cardiovascular care: recommendations of the European Association of Cardiovascular Imaging and the Acute Cardiovascular Care Association. European Heart Journal Acute Cardiovascular Care. 4(1):3-5, 2015 Feb.
- **42.** Lim SH, Sayre MR, Gibler WB. 2-D echocardiography prediction of adverse events in ED patients with chest pain. Am J Emerg Med. 2003; 21(2):106-110.
- **43.** Innocenti F, Cerabona P, Donnini C, Conti A, Zanobetti M, Pini R. Long-term prognostic value of stress echocardiography in patients presenting to the ED with spontaneous chest pain. Am J Emerg Med. 32(7):731-6, 2014 Jul.
- **44.** 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. 100(7):1068-73, 2007 Oct 01.
- **45.** Hartlage G, Janik M, Anadiotis A, et al. Prognostic value of adenosine stress cardiovascular magnetic resonance and dobutamine stress echocardiography in patients with low-risk chest pain. Int J Cardiovasc Imaging. 28(4):803-12, 2012 Apr.
- **46.** Aldous S, Richards AM, Cullen L, Pickering JW, Than M. The incremental value of stress testing in patients with acute chest pain beyond serial cardiac troponin testing. Emerg Med J. 33(5):319-24, 2016 May.
- **47.** Yao SS, Bangalore S, Chaudhry FA. Prognostic implications of stress echocardiography and impact on patient outcomes: an effective gatekeeper for coronary angiography and revascularization. J Am Soc Echocardiogr. 23(8):832-9, 2010 Aug.
- **48.** Frenkel O, Riguzzi C, Nagdev A. Identification of high-risk patients with acute coronary syndrome using point-of-care echocardiography in the ED. Am J Emerg Med. 32(6):670-2, 2014 Jun.
- **49.** 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. 23(12):1225-30, 2010 Dec.
- **50.** Gaibazzi N, Squeri A, Reverberi C, et al. Contrast stress-echocardiography predicts cardiac events in patients with suspected acute coronary syndrome but nondiagnostic electrocardiogram and normal 12-hour troponin. J Am Soc Echocardiogr. 24(12):1333-41, 2011 Dec.
- **51.** 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(1):129-136.
- **52.** Rinkevich D, Kaul S, Wang XQ, et al. Regional left ventricular perfusion and function in patients presenting to the emergency department with chest pain and no ST-segment elevation. Eur Heart J. 26(16):1606-11, 2005 Aug.
- **53.** Wei K.. Utility contrast echocardiography in the emergency department. [Review] [44 refs]. JACC Cardiovasc Imaging. 3(2):197-203, 2010 Feb.
- **54.** Dahlslett T, Karlsen S, Grenne B, et al. Early assessment of strain echocardiography can accurately exclude significant coronary artery stenosis in suspected non-ST-segment

- elevation acute coronary syndrome. J Am Soc Echocardiogr. 27(5):512-9, 2014 May.
- **55.** Eek C, Grenne B, Brunvand H, et al. Strain echocardiography predicts acute coronary occlusion in patients with non-ST-segment elevation acute coronary syndrome. Eur J Echocardiogr. 11(6):501-8, 2010 Jul.
- **56.** Sarvari SI, Haugaa KH, Zahid W, et al. Layer-specific quantification of myocardial deformation by strain echocardiography may reveal significant CAD in patients with non-ST-segment elevation acute coronary syndrome. JACC Cardiovasc Imaging. 6(5):535-44, 2013 May.
- **57.** Schroeder J, Hamada S, Grundlinger N, et al. Myocardial deformation by strain echocardiography identifies patients with acute coronary syndrome and non-diagnostic ECG presenting in a chest pain unit: a prospective study of diagnostic accuracy. Clin. res. cardiol.. 105(3):248-56, 2016 Mar.
- **58.** Kuhl HP, Hanrath P. The impact of transesophageal echocardiography on daily clinical practice. Eur J Echocardiogr. 2004; 5(6):455-468.
- 59. Hendel RC, Patel MR, Kramer CM, et al. ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology. [Review] [13 refs]. J Am Coll Cardiol. 48(7):1475-97, 2006 Oct 03.
- **60.** 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(18):1642-1650.
- **61.** Goldstein JA, Gallagher MJ, O'Neill WW, Ross MA, O'Neil BJ, Raff GL. A randomized controlled trial of multi-slice coronary computed tomography for evaluation of acute chest pain. J Am Coll Cardiol. 2007; 49(8):863-871.
- **62.** Hoffmann U, Nagurney JT, Moselewski F, et al. Coronary multidetector computed tomography in the assessment of patients with acute chest pain. Circulation. 2006; 114(21):2251-2260.
- **63.** Rubinshtein R, Halon DA, Gaspar T, et al. Usefulness of 64-slice multidetector computed tomography in diagnostic triage of patients with chest pain and negative or nondiagnostic exercise treadmill test result. Am J Cardiol. 2007; 99(7):925-929.
- **64.** Stillman AE, Oudkerk M, Ackerman M, et al. Use of multidetector computed tomography for the assessment of acute chest pain: a consensus statement of the North American Society of Cardiac Imaging and the European Society of Cardiac Radiology. Eur Radiol. 2007; 17(8):2196-2207.
- **65.** Levsky JM, Spevack DM, Travin MI, et al. Coronary Computed Tomography Angiography Versus Radionuclide Myocardial Perfusion Imaging in Patients With Chest Pain Admitted to Telemetry: A Randomized Trial. Annals of Internal Medicine. 163(3):174-83, 2015 Aug

- 04.Ann Intern Med. 163(3):174-83, 2015 Aug 04.
- **66.** Linde JJ, Hove JD, Sorgaard M, et al. Long-Term Clinical Impact of Coronary CT Angiography in Patients With Recent Acute-Onset Chest Pain: The Randomized Controlled CATCH Trial. Jacc: Cardiovascular Imaging. 8(12):1404-1413, 2015 Dec.JACC Cardiovasc Imaging. 8(12):1404-1413, 2015 Dec.
- **67.** Pena E, Rubens F, Stiell I, Peterson R, Inacio J, Dennie C. Efficiency and safety of coronary CT angiography compared to standard care in the evaluation of patients with acute chest pain: a Canadian study. EMERG. RADIOL.. 23(4):345-52, 2016 Aug.
- **68.** Truong QA, Schulman-Marcus J, Zakroysky P, et al. Coronary CT Angiography Versus Standard Emergency Department Evaluation for Acute Chest Pain and Diabetic Patients: Is There Benefit With Early Coronary CT Angiography? Results of the Randomized Comparative Effectiveness ROMICAT II Trial. Journal of the American Heart Association. 5(3):e003137, 2016 Mar 22.
- **69.** 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. 58(14):1414-22, 2011 Sep 27.
- **70.** Hoffmann U, Truong QA, Schoenfeld DA, et al. Coronary CT angiography versus standard evaluation in acute chest pain. N Engl J Med. 367(4):299-308, 2012 Jul 26.
- **71.** 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(15):1393-1403.
- **72.** Takakuwa KM, Keith SW, Estepa AT, Shofer FS. A meta-analysis of 64-section coronary CT angiography findings for predicting 30-day major adverse cardiac events in patients presenting with symptoms suggestive of acute coronary syndrome. Acad Radiol. 18(12):1522-8, 2011 Dec.
- **73.** Budoff MJ, Dowe D, Jollis JG, et al. Diagnostic performance of 64-multidetector row coronary computed tomographic angiography for evaluation of coronary artery stenosis in individuals without known coronary artery disease: results from the prospective multicenter ACCURACY (Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography) trial. J Am Coll Cardiol. 2008;52(21):1724-1732.
- **74.** Cury RC, Budoff M, Taylor AJ. Coronary CT angiography versus standard of care for assessment of chest pain in the emergency department. [Review]. J Cardiovasc Comput Tomogr. 7(2):79-82, 2013 Mar-Apr.
- **75.** Cury RC, Feuchtner GM, Batlle JC, et al. Triage of patients presenting with chest pain to the emergency department: implementation of coronary CT angiography in a large urban health care system. AJR Am J Roentgenol. 200(1):57-65, 2013 Jan.
- **76.** Romero J, Husain SA, Holmes AA, et al. Non-invasive assessment of low risk acute chest pain in the emergency department: A comparative meta-analysis of prospective studies. Int J Cardiol. 187:565-80, 2015.
- **77.** Body R, Burrows G, Carley S, Lewis PS. Rapid exclusion of acute myocardial infarction in patients with undetectable troponin using a sensitive troponin I assay. Ann Clin Biochem. 52(Pt 5):543-9, 2015 Sep.

- **78.** Dedic A, Lubbers MM, Schaap J, et al. Coronary CT Angiography for Suspected ACS in the Era of High-Sensitivity Troponins: Randomized Multicenter Study. Journal of the American College of Cardiology. 67(1):16-26, 2016 Jan 05.
- **79.** Dedic A, Nieman K, Hoffmann U, Ferencik M. Is there still a role for cardiac CT in the emergency department in the era of highly-sensitive troponins?. [Review]. Minerva Cardioangiol. 65(3):214-224, 2017 Jun.
- **80.** Ferencik M, Liu T, Mayrhofer T, et al. hs-Troponin I Followed by CT Angiography Improves Acute Coronary Syndrome Risk Stratification Accuracy and Work-Up in Acute Chest Pain Patients: Results From ROMICAT II Trial. Jacc: Cardiovascular Imaging. 8(11):1272-1281, 2015 Nov.
- **81.** Neglia D, Rovai D, Caselli C, et al. Detection of significant coronary artery disease by noninvasive anatomical and functional imaging. Circ Cardiovasc Imaging. 8(3), 2015 Mar.
- **82.** Chen MY, Rochitte CE, Arbab-Zadeh A, et al. Prognostic Value of Combined CT Angiography and Myocardial Perfusion Imaging versus Invasive Coronary Angiography and Nuclear Stress Perfusion Imaging in the Prediction of Major Adverse Cardiovascular Events: The CORE320 Multicenter Study. Radiology. 284(1):55-65, 2017 Jul.
- **83.** Feuchtner GM, Plank F, Pena C, et al. Evaluation of myocardial CT perfusion in patients presenting with acute chest pain to the emergency department: comparison with SPECT-myocardial perfusion imaging. Heart. 98(20):1510-7, 2012 Oct.
- **84.** Linde JJ, Sorgaard M, Kuhl JT, et al. Prediction of clinical outcome by myocardial CT perfusion in patients with low-risk unstable angina pectoris. Int J Cardiovasc Imaging. 33(2):261-270, 2017 Feb.
- **85.** Rochitte CE, George RT, Chen MY, et al. Computed tomography angiography and perfusion to assess coronary artery stenosis causing perfusion defects by single photon emission computed tomography: the CORE320 study. Eur Heart J 2014;35:1120-30.
- **86.** Branch KR, Busey J, Mitsumori LM, et al. Diagnostic performance of resting CT myocardial perfusion in patients with possible acute coronary syndrome. AJR Am J Roentgenol. 200(5):W450-7, 2013 May.
- **87.** Pursnani A, Lee AM, Mayrhofer T, et al. Early resting myocardial computed tomography perfusion for the detection of acute coronary syndrome in patients with coronary artery disease. Circulation. Cardiovascular imaging. 8(3):e002404, 2015 Mar.
- **88.** Coenen A, Rossi A, Lubbers MM, et al. Integrating CT Myocardial Perfusion and CT-FFR in the Work-Up of Coronary Artery Disease. JACC Cardiovasc Imaging. 10(7):760-770, 2017 Jul.
- **89.** Douglas PS, De Bruyne B, Pontone G, et al. 1-Year Outcomes of FFRCT-Guided Care in Patients With Suspected Coronary Disease: The PLATFORM Study. J Am Coll Cardiol. 68(5):435-45, 2016 Aug 02.
- **90.** Koo BK, Erglis A, Doh JH, et al. Diagnosis of ischemia-causing coronary stenoses by noninvasive fractional flow reserve computed from coronary computed tomographic angiograms. Results from the prospective multicenter DISCOVER-FLOW (Diagnosis of Ischemia-Causing Stenoses Obtained Via Noninvasive Fractional Flow Reserve) study. J Am Coll Cardiol 2011;58:1989-97.

- **91.** Min JK, Leipsic J, Pencina MJ, et al. Diagnostic accuracy of fractional flow reserve from anatomic CT angiography. Jama 2012;308:1237-45.
- **92.** Norgaard BL, Leipsic J, Gaur S, et al. Diagnostic performance of noninvasive fractional flow reserve derived from coronary computed tomography angiography in suspected coronary artery disease: the NXT trial (Analysis of Coronary Blood Flow Using CT Angiography: Next Steps). J Am Coll Cardiol 2014;63:1145-55.
- **93.** Pontone G, Andreini D, Guaricci AI, et al. Rationale and design of the PERFECTION (comparison between stress cardiac computed tomography PERfusion versus Fractional flow rEserve measured by Computed Tomography angiography In the evaluation of suspected cOroNary artery disease) prospective study. J Cardiovasc Comput Tomogr. 10(4):330-4, 2016 Jul-Aug.
- **94.** Laudon DA, Behrenbeck TR, Wood CM, et al. Computed tomographic coronary artery calcium assessment for evaluating chest pain in the emergency department: long-term outcome of a prospective blind study. Mayo Clin Proc. 85(4):314-22, 2010 Apr.
- **95.** Chaikriangkrai K, Palamaner Subash Shantha G, Jhun HY, et al. Prognostic Value of Coronary Artery Calcium Score in Acute Chest Pain Patients Without Known Coronary Artery Disease: Systematic Review and Meta-analysis. [Review]. Ann Emerg Med. 68(6):659-670, 2016 12.
- **96.** Nance JW Jr, Schlett CL, Schoepf UJ, et al. Incremental prognostic value of different components of coronary atherosclerotic plaque at cardiac CT angiography beyond coronary calcification in patients with acute chest pain. Radiology. 264(3):679-90, 2012 Sep.
- **97.** Hecht HS.. Coronary artery calcium scanning: past, present, and future. [Review]. JACC Cardiovasc Imaging. 8(5):579-596, 2015 May.
- **98.** Hinzpeter R, Higashigaito K, Morsbach F, et al. Coronary artery calcium scoring for ruling-out acute coronary syndrome in chest pain CT. Am J Emerg Med. 35(10):1565-1567, 2017 Oct.
- **99.** Tota-Maharaj R, McEvoy JW, Blaha MJ, Silverman MG, Nasir K, Blumenthal RS. Utility of coronary artery calcium scoring in the evaluation of patients with chest pain. [Review]. Crit. pathw. cardiol.. 11(3):99-106, 2012 Sep.
- **100.** Yerramasu A, Lahiri A, Venuraju S, et al. Diagnostic role of coronary calcium scoring in the rapid access chest pain clinic: prospective evaluation of NICE guidance. Eur Heart J Cardiovasc Imaging. 15(8):886-92, 2014 Aug.
- **101.** Watanabe T, Furuse Y, Ohta Y, Kato M, Ogawa T, Yamamoto K. The Effectiveness of Non-ECG-Gated Contrast-Enhanced Computed Tomography for the Diagnosis of Non-ST Segment Elevation Acute Coronary Syndrome. International Heart Journal. 57(5):558-64, 2016 Sep 28.
- **102.** Yamazaki M, Higuchi T, Shimokoshi T, et al. Acute coronary syndrome: evaluation of detection capability using non-electrocardiogram-gated parenchymal phase CT imaging. Jpn J Radiol. 34(5):331-8, 2016 May.
- **103.** Yoo SM, Chun EJ, Lee HY, Min D, White CS. Computed Tomography Diagnosis of Nonspecific Acute Chest Pain in the Emergency Department: From Typical Acute Coronary Syndrome to Various Unusual Mimics. [Review]. J Thorac Imaging. 32(1):26-35, 2017 Jan.

- **104.** Kanza RE, Allard C, Berube M. Cardiac findings on non-gated chest computed tomography: A clinical and pictorial review. [Review]. Eur J Radiol. 85(2):435-51, 2016 Feb.
- **105.** Kajander S, Joutsiniemi E, Saraste M, et al. Cardiac positron emission tomography/computed tomography imaging accurately detects anatomically and functionally significant coronary artery disease. Circulation. 122(6):603-13, 2010 Aug 10.
- **106.** Nandalur KR, Dwamena BA, Choudhri AF, Nandalur SR, Reddy P, Carlos RC. Diagnostic performance of positron emission tomography in the detection of coronary artery disease: a meta-analysis. Acad Radiol. 15(4):444-51, 2008 Apr.
- **107.** Groves AM, Speechly-Dick ME, Kayani I, et al. First experience of combined cardiac PET/64-detector CT angiography with invasive angiographic validation. Eur J Nucl Med Mol Imaging. 36(12):2027-33, 2009 Dec.
- **108.** Namdar M, Hany TF, Koepfli P, et al. Integrated PET/CT for the assessment of coronary artery disease: a feasibility study. J Nucl Med 2005;46:930-5.
- **109.** Jaarsma C, Leiner T, Bekkers SC, et al. Diagnostic performance of noninvasive myocardial perfusion imaging using single-photon emission computed tomography, cardiac magnetic resonance, and positron emission tomography imaging for the detection of obstructive coronary artery disease: a meta-analysis. J Am Coll Cardiol. 2012;59(19):1719-1728.
- **110.** Lerakis S, McLean DS, Anadiotis AV, et al. Prognostic value of adenosine stress cardiovascular magnetic resonance in patients with low-risk chest pain. J Cardiovasc Magn Reson. 2009; 11:37.
- **111.** Vogel-Claussen J, Skrok J, Dombroski D, et al. Comprehensive adenosine stress perfusion MRI defines the etiology of chest pain in the emergency room: Comparison with nuclear stress test. J Magn Reson Imaging. 2009; 30(4):753-762.
- **112.** Ahmad IG, Abdulla RK, Klem I, et al. Comparison of stress cardiovascular magnetic resonance imaging (CMR) with stress nuclear perfusion for the diagnosis of coronary artery disease. J Nucl Cardiol. 23(2):287-97, 2016 Apr.
- **113.** Macwar RR, Williams BA, Shirani J. Prognostic value of adenosine cardiac magnetic resonance imaging in patients presenting with chest pain. Am J Cardiol. 112(1):46-50, 2013 Jul 01.
- **114.** Miller CD, Case LD, Little WC, et al. Stress CMR reduces revascularization, hospital readmission, and recurrent cardiac testing in intermediate-risk patients with acute chest pain. JACC Cardiovasc Imaging. 6(7):785-94, 2013 Jul.
- **115.** Charoenpanichkit C, Hundley WG. The 20 year evolution of dobutamine stress cardiovascular magnetic resonance. [Review]. J Cardiovasc Magn Reson. 12:59, 2010 Oct 26.
- **116.** Korosoglou G, Elhmidi Y, Steen H, et al. Prognostic value of high-dose dobutamine stress magnetic resonance imaging in 1,493 consecutive patients: assessment of myocardial wall motion and perfusion. J Am Coll Cardiol. 2010;56(15):1225-1234.
- **117.** Bodi V, Sanchis J, Lopez-Lereu MP, et al. Prognostic value of dipyridamole stress cardiovascular magnetic resonance imaging in patients with known or suspected coronary artery disease. J Am Coll Cardiol. 50(12):1174-9, 2007 Sep 18.
- 118. Bodi V, Sanchis J, Lopez-Lereu MP, et al. Prognostic and therapeutic implications of

- dipyridamole stress cardiovascular magnetic resonance on the basis of the ischaemic cascade. Heart. 95(1):49-55, 2009 Jan.
- **119.** Greenwood JP, Maredia N, Younger JF, et al. Cardiovascular magnetic resonance and single-photon emission computed tomography for diagnosis of coronary heart disease (CE-MARC): a prospective trial. Lancet. 2012;379(9814):453-460.
- **120.** Schwitter J, Wacker CM, van Rossum AC, et al. MR-IMPACT: comparison of perfusion-cardiac magnetic resonance with single-photon emission computed tomography for the detection of coronary artery disease in a multicentre, multivendor, randomized trial. Eur Heart J. 29(4):480-9, 2008 Feb.
- **121.** Hussain ST, Paul M, Plein S, et al. Design and rationale of the MR-INFORM study: stress perfusion cardiovascular magnetic resonance imaging to guide the management of patients with stable coronary artery disease. J Cardiovasc Magn Reson. 14:65, 2012 Sep 19.
- **122.** Kwong RY, Schussheim AE, Rekhraj S, et al. Detecting acute coronary syndrome in the emergency department with cardiac magnetic resonance imaging. Circulation. 2003;107(4):531-537.
- **123.** Plein S, Greenwood JP, Ridgway JP, Cranny G, Ball SG, Sivananthan MU. Assessment of non-ST-segment elevation acute coronary syndromes with cardiac magnetic resonance imaging. J Am Coll Cardiol. 44(11):2173-81, 2004 Dec 07.
- **124.** Cury RC, Shash K, Nagurney JT, et al. Cardiac magnetic resonance with T2-weighted imaging improves detection of patients with acute coronary syndrome in the emergency department. Circulation. 2008;118(8):837-844.
- **125.** Raman SV, Simonetti OP, Winner MW 3rd, et al. Cardiac magnetic resonance with edema imaging identifies myocardium at risk and predicts worse outcome in patients with non-ST-segment elevation acute coronary syndrome. J Am Coll Cardiol. 55(22):2480-8, 2010 Jun 01.
- **126.** Lockie T, Nagel E, Redwood S, Plein S. Use of cardiovascular magnetic resonance imaging in acute coronary syndromes. [Review] [104 refs]. Circulation. 119(12):1671-81, 2009 Mar 31.
- **127.** Pufulete M, Brierley RC, Bucciarelli-Ducci C, et al. Formal consensus to identify clinically important changes in management resulting from the use of cardiovascular magnetic resonance (CMR) in patients who activate the primary percutaneous coronary intervention (PPCI) pathway. [Review]. BMJ Open. 7(6):e014627, 2017 Jun 22.
- **128.** Dastidar AG, Rodrigues JC, Ahmed N, Baritussio A, Bucciarelli-Ducci C. The Role of Cardiac MRI in Patients with Troponin-Positive Chest Pain and Unobstructed Coronary Arteries. [Review]. Curr. cardiovasc. imaging rep.. 8(8):28, 2015.
- **129.** Pathik B, Raman B, Mohd Amin NH, et al. Troponin-positive chest pain with unobstructed coronary arteries: incremental diagnostic value of cardiovascular magnetic resonance imaging. European heart journal cardiovascular Imaging. 17(10):1146-52, 2016 Oct. Eur Heart J Cardiovasc Imaging. 17(10):1146-52, 2016 Oct.
- **130.** Dall'Armellina E, Piechnik SK, Ferreira VM, et al. Cardiovascular magnetic resonance by non contrast T1-mapping allows assessment of severity of injury in acute myocardial infarction. J Cardiovasc Magn Reson. 14:15, 2012 Feb 06.

- **131.** Saremi F.. Cardiac MR Imaging in Acute Coronary Syndrome: Application and Image Interpretation. [Review]. Radiology. 282(1):17-32, 2017 Jan.
- **132.** Bluemke DA, Achenbach S, Budoff M, et al. Noninvasive coronary artery imaging: magnetic resonance angiography and multidetector computed tomography angiography: a scientific statement from the american heart association committee on cardiovascular imaging and intervention of the council on cardiovascular radiology and intervention, and the councils on clinical cardiology and cardiovascular disease in the young. Circulation. 2008; 118(5):586-606.
- **133.** American College of Cardiology Foundation Task Force on Expert Consensus Documents, Hundley WG, Bluemke DA, et al. ACCF/ACR/AHA/NASCI/SCMR 2010 expert consensus document on cardiovascular magnetic resonance: a report of the American College of Cardiology Foundation Task Force on Expert Consensus Documents. [Review] [426 refs]. J Am Coll Cardiol. 55(23):2614-62, 2010 Jun 08.
- **134.** Kato S, Kitagawa K, Ishida N, et al. Assessment of coronary artery disease using magnetic resonance coronary angiography: a national multicenter trial. J Am Coll Cardiol. 56(12):983-91, 2010 Sep 14.
- **135.** Dweck MR, Puntman V, Vesey AT, Fayad ZA, Nagel E. MR Imaging of Coronary Arteries and Plaques. [Review]. JACC Cardiovasc Imaging. 9(3):306-16, 2016 Mar.
- 136. Dracup K, Alonzo AA, Atkins JM, et al. The physician's role in minimizing prehospital delay in patients at high risk for acute myocardial infarction: recommendations from the National Heart Attack Alert Program. Working Group on Educational Strategies To Prevent Prehospital Delay in Patients at High Risk for Acute Myocardial Infarction. [Review] [61 refs]. Ann Intern Med. 126(8):645-51, 1997 Apr 15.
- **137.** Krumholz HM, Bradley EH, Nallamothu BK, et al. A campaign to improve the timeliness of primary percutaneous coronary intervention: Door-to-Balloon: An Alliance for Quality. [Review] [28 refs]. JACC Cardiovasc Interv. 1(1):97-104, 2008 Feb.
- **138.** 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.[Erratum appears in Circulation. 2013 Dec 24;128(25):e481]. Circulation. 127(4):e362-425, 2013 Jan 29.
- **139.** 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.[Erratum appears in J Am Coll Cardiol. 2014 Dec 23;64(24):2713-4. Dosage error in article text]. J Am Coll Cardiol. 64(24):e139-e228, 2014 Dec 23.
- **140.** Korley FK, Jaffe AS. Preparing the United States for high-sensitivity cardiac troponin assays. [Review]. J Am Coll Cardiol. 61(17):1753-8, 2013 Apr 30.
- **141.** Damman P, Hirsch A, Windhausen F, Tijssen JG, de Winter RJ, ICTUS Investigators. 5-year clinical outcomes in the ICTUS (Invasive versus Conservative Treatment in Unstable coronary Syndromes) trial a randomized comparison of an early invasive versus selective invasive management in patients with non-ST-segment elevation acute coronary syndrome. J Am Coll Cardiol. 55(9):858-64, 2010 Mar 02.

- **142.** Mehta SR, Granger CB, Boden WE, et al. Early versus delayed invasive intervention in acute coronary syndromes. N Engl J Med. 360(21):2165-75, 2009 May 21.
- **143.** O'Donoghue M, Boden WE, Braunwald E, et al. Early invasive vs conservative treatment strategies in women and men with unstable angina and non-ST-segment elevation myocardial infarction: a meta-analysis. JAMA. 300(1):71-80, 2008 Jul 02.
- **144.** Kim HW, Farzaneh-Far A, Kim RJ. Cardiovascular magnetic resonance in patients with myocardial infarction: current and emerging applications. [Review] [114 refs]. J Am Coll Cardiol. 55(1):1-16, 2009 Dec 29.
- **145.** Emrich T, Emrich K, Abegunewardene N, et al. Cardiac MR enables diagnosis in 90% of patients with acute chest pain, elevated biomarkers and unobstructed coronary arteries. Br J Radiol. 88(1049):20150025, 2015 May.
- **146.** Mahmarian JJ, Shaw LJ, Filipchuk NG, et al. A multinational study to establish the value of early adenosine technetium-99m sestamibi myocardial perfusion imaging in identifying a low-risk group for early hospital discharge after acute myocardial infarction. J Am Coll Cardiol. 48(12):2448-57, 2006 Dec 19.
- **147.** Shaw LJ, Hachamovitch R, Berman DS, et al. The economic consequences of available diagnostic and prognostic strategies for the evaluation of stable angina patients: an observational assessment of the value of precatheterization ischemia. Economics of Noninvasive Diagnosis (END) Multicenter Study Group. J Am Coll Cardiol. 33(3):661-9, 1999 Mar.
- **148.** American College of Radiology. ACR Appropriateness Criteria® Radiation Dose Assessment Introduction. Available at: https://edge.sitecorecloud.io/americancoldf5f-acrorgf92a-productioncb02-3650/media/ACR/Files/Clinical/Appropriateness-Criteria/ACR-Appropriateness-Criteria-Radiation-Dose-Assessment-Introduction.pdf.

#### **Disclaimer**

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

<sup>a</sup>Miami Cardiac and Vascular Institute and Baptist Health of South Florida, Miami, Florida. <sup>b</sup>Panel Chair, Cleveland Clinic Florida, Weston, Florida. <sup>c</sup>Panel Vice-Chair, Cleveland Clinic, Cleveland, Ohio. <sup>d</sup>National Institutes of Health, Bethesda, Maryland; Society for Cardiovascular Magnetic Resonance. <sup>e</sup>University of Michigan Health System, Ann Arbor, Michigan; Commission on Nuclear Medicine and

Molecular Imaging. <sup>f</sup>University of Wisconsin, Madison, Wisconsin. <sup>9</sup>The Ohio State University Wexner Medical Center, Columbus, Ohio. <sup>h</sup>Toronto General Hospital, University of Toronto, Toronto, Ontario, Canada. <sup>i</sup>The Ottawa Hospital, University of Ottawa, Ottawa, Ontario, Canada. <sup>j</sup>Sanger Heart and Vascular Institute, Charlotte, North Carolina; American Society of Echocardiography. <sup>k</sup>Vancouver General Hospital, Vancouver, British Columbia, Canada; Committee on Emergency Radiology-GSER. <sup>l</sup>Nationwide Children's Hospital, Columbus, Ohio. <sup>m</sup>UT Southwestern Medical Center, Dallas, Texas. <sup>n</sup>University of Alabama at Birmingham, Birmingham, Alabama. <sup>o</sup>UC San Diego Health, San Diego, California; American College of Emergency Physicians. <sup>p</sup>University of Virginia Health Center, Charlottesville, Virginia; Society of Cardiovascular Computed Tomography. <sup>q</sup>Ascension Healthcare Wisconsin, Milwaukee, Wisconsin; American Society of Nuclear Cardiology. <sup>r</sup>Mayo Clinic, Rochester, Minnesota. <sup>s</sup>Johns Hopkins Medical Institute, Baltimore, Maryland. <sup>t</sup>Specialty Chair, UT Southwestern Medical Center, Dallas, Texas.