American College of Radiology
ACR Appropriateness Criteria®

Chronic Chest Pain-Noncardiac Etiology Unlikely: Low to Intermediate Probability of Coronary Artery Disease

Variant: 1 Chronic chest pain, noncardiac etiology unlikely: low to intermediate probability of coronary artery disease. Initial imaging.

Procedure	Appropriateness Category	Relative Radiation Level
US echocardiography transthoracic stress	Usually Appropriate	O
MRI heart with function and vasodilator stress perfusion without and with IV contrast	Usually Appropriate	O
CTA coronary arteries with IV contrast	Usually Appropriate	☢☢☢
SPECT or SPECT/CT MPI stress only	Usually Appropriate	☢☢☢
Rb-82 PET/CT MPI rest and stress	Usually Appropriate	☢☢☢☢
SPECT or SPECT/CT MPI rest and stress	Usually Appropriate	☢☢☢☢
US echocardiography transthoracic resting	May Be Appropriate	O
MRA coronary arteries without and with IV contrast	May Be Appropriate	O
MRI heart function and morphology without IV contrast	May Be Appropriate	O
MRI heart with function and inotropic stress without and with IV contrast	May Be Appropriate	O
MRI heart with function and inotropic stress without IV contrast	May Be Appropriate	O
CT chest with IV contrast	May Be Appropriate	☢☢☢
CT coronary calcium	May Be Appropriate	☢☢☢
Arteriography coronary	Usually Not Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
CT chest without IV contrast	Usually Not Appropriate	☢☢☢
SPECT or SPECT/CT MPI rest only	Usually Not Appropriate	☢☢☢

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Summary of Literature Review

Introduction/Background

Chronic chest pain (CCP) with low to intermediate probability of coronary artery disease (CAD) can arise from cardiac and noncardiac etiologies. While there are multiple potential noncardiac causes of CCP, such as costochondritis, arthritic or degenerative diseases, prior trauma, primary or metastatic tumors, pleural disease, or gastrointestinal causes, the scope of this document is focused on evaluating chest pain when a cardiac etiology is the concern.

When CCP with a cardiac origin is suspected, it is helpful to estimate the patient's probability of CAD. A clinical risk assessment can stratify the patients into low probability, intermediate probability, and high probability of CAD. Multiple clinical risk assessment tools are available, including the Framingham risk score, Diamond Forrester method, and Duke Clinical Score. While these tools are helpful in asymptomatic patients, they may not best stratify a patient's risk, particularly in patients who are symptomatic [1,2]. Coronary calcium score (CCS), although traditionally applied to asymptomatic patients, may better stratify patients at risk [3].

Multiple imaging tools can be used to evaluate CCP in symptomatic patients with low to intermediate probability for CAD. The imaging modalities available include: (1) multidetector coronary computed tomography angiography (CCTA); (2) stress and rest radionuclide single-photon emission computed tomography (SPECT) myocardial perfusion imaging (MPI); (3) catheter-based invasive coronary angiography (ICA) with or without ventriculography; (4) chest radiography; (5) stress echocardiography; (6) PET; and (7) cardiac MRI and MR angiography (MRA).

Special Imaging Considerations

Advances in cardiac CT imaging technology have further reduced radiation dose in CCTA examinations [4]. New and available dose-reducing techniques include prospective triggering [5-7], iterative reconstruction algorithms [8], long z-axis coverage, and high-pitch spiral acquisition [9]. However, these newer low-dose techniques may not be available or appropriate for all patients. Although these techniques can reduce patient radiation dose, there may be patients for whom these radiation dose techniques are not optimal. In all cases, the imaging physician must select the appropriate combination of imaging parameters to acquire a diagnostic examination at a radiation dose that is as low as reasonably achievable.

Discussion of Procedures by Variant

Variant 1: Chronic chest pain, noncardiac etiology unlikely: low to intermediate probability of coronary artery disease. Initial imaging.

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A. CTA Coronary Arteries

In patients with low to intermediate probability of CAD, multidetector CCTA can be performed for direct coronary artery evaluation. CCTA has been shown to be of value when evaluating patients with CAD because of its high negative predictive value. The use of CCTA has advantages when compared to other testing modalities. CCTA has superior diagnostic accuracy compared to other examinations, may identify high-probability patients based on plaque morphology, and allow for more appropriate selection of patients for downstream testing, including ICA, compared to other noninvasive strategies. The use of CCTA may decrease health care use and improve outcomes, including a decreased risk of myocardial infarction [10-17]. CCTA has also shown promise in directing appropriate patients for ICA compared to noninvasive strategies, may reduce downstream noninvasive testing, identify high-probability patients based on plaque morphology, and have superior diagnostic accuracy compared to other diagnostic tests [18,19].

Specifically, recent trials from the Computed Tomography versus Exercise Testing in Suspected Coronary Artery Disease (CRESCENT), the Scottish COmputed Tomography of the HEART (SCOT-

HEART), the Prospective Multicenter Imaging Study for Evaluation of Chest Pain trial (PROMISE trial), the Cardiac CT for the Assessment of Chest Pain and Plaque (CAPP) study, and COronary CT Angiography EvaluatioN For Clinical Outcomes: An InteRnational Multicenter Registry (CONFIRM) registry provide additional support for the use of CCTA into the diagnostic algorithm when evaluating patients with chest pain.

The CRESCENT investigators suggest that the use of CCTA in combination with calcium scoring may allow for a structured protocol that allows a diagnosis to be reached faster with no increase in the referral rate for ICA [20]. The CCTA can also reduce the time to diagnosis and determine which patients need invasive testing [12,13,21-23]. Specifically in patients in whom angina that is due to CAD was suspected, the SCOT-HEART investigators showed that CCTA clarified the diagnosis by providing added certainty, enabling targeted interventions, and potentially reducing the risk of future myocardial infarction [24].

The PROMISE investigators evaluated patients with stable chest pain to either CCTA or functional testing. Their work has shown that patients who underwent CCTA had a lower risk of death and lower risk of myocardial infarction (not leading to a fatality) compared to patients who underwent conventional functional testing. The investigators suggest that CCTA can be a safe alternative to functional testing in a low-risk population [25,26].

CCTA has also provided prognostic information beyond that of clinical risk scores [27]. Data from the CAPP and CONFIRM investigators have provided additional information. The CAPP investigators have shown that patients undergoing CCTA identified significant disease, underwent more revascularizations, less diagnostic testing, and fewer admissions for chest pain [28]. The CONFIRM investigators have also shown that CCTA better predicted risk compared to well-established clinical risk scores and reclassified approximately one [29].

CCTA has the potential to characterize plaque and has the potential to identify "high-risk" plaque potentially allowing for patient risk stratification [30-32]. New technology may allow for noninvasive assessment of lesion-specific ischemia (CT fractional flow reserve) [33-36] with the added promise to better determine the functional significance of coronary lesions and determine which lesions are suited for downstream ICA [37]. Recent work from the Prospective LongitudinAl Trial of FFR_{CT}: Outcome and Resource Impacts (PLATFORM) investigators and others suggests that CCTA integrated with a noninvasive CT fractional flow reserve assessment may better select patients for ICA without negatively impacting mortality and appropriately select patients who need revascularization [38-40].

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B. CT Chest

When CAD and other cardiac etiologies of chest pain, such as aortic disease pericardial disease, are suspected, a chest CT may be appropriate.

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C. SPECT or SPECT/CT MPI

Stress SPECT MPI [41] is a central part of the diagnostic pathway when evaluating patients with CCP. A SPECT MPI scan is performed with either exercise-induced or pharmacologically induced

stress to demonstrate myocardial perfusion or contraction abnormalities.

Use of stress imaging can be performed rapidly and increasingly through protocol optimization, with lower radiation doses [42]. Patients who undergo SPECT imaging have outcomes similar to CCTA in terms of outcomes [25,43]. In addition, the use of stress MPI improved clinical decision making for chest pain patients [44].

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D. CT Coronary Calcium

CCS can be used as a diagnostic tool when evaluating patients with chest pain [45]. In patients presenting with stable angina, a positive CCS score is more accurate than clinical risk stratification tools, such as the Diamond Forrester risk stratification tool, for determining which patients have CAD [46]. CCS is also predictive of which patients may have significant stenosis and can be used to determine which patients need additional diagnostic testing and may benefit from initiation of medical treatment [46,47]. However, a CCS of "zero," showing no calcified coronary plaque, does not exclude acute coronary syndrome, significant coronary plaque burden, or plaque, which suggests that additional testing beyond CCS may be needed [48-50].

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E. US Echocardiography Transthoracic Stress

When echocardiography is performed, stress contraction abnormalities are induced by either exercise or inotropic stimulation. In any situation where a SPECT MPI study cannot be performed, an exercise-stress or dobutamine-stress echocardiogram may be substituted [51,52]. Stress echocardiography is used to evaluate for wall motion abnormalities and can provide data regarding flow reserve, which can aid in patient risk stratification [53].

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F. US Echocardiography Transthoracic Resting

In certain cases, if valvular heart disease, hypertrophic cardiomyopathy, or pericardial disease is the primary diagnostic concern, an echocardiogram at rest may be the preferred examination. The use of nonstress echocardiography in patients with stable chest pain when coronary artery disease is suspected may not reveal additional diagnostic information [54].

Variant 1: Chronic chest pain, noncardiac etiology unlikely: low to intermediate probability of coronary artery disease. Initial imaging.
G. MRI Heart

MRI is an emerging technology, and its clinical applications to cardiac imaging continue to develop. Currently, stress cardiac MRI and coronary MRA are available to diagnose CAD.

Cardiac MRI without stress can be performed to evaluate valvular heart disease, nonischemic etiologies of chest pain, such as hypertrophic cardiomyopathy, or evaluate for pericardial disease.

Stress cardiac MRI can be performed with dobutamine, adenosine, or dipyridamole. Dobutamine-stress functional cardiac MRI may also play a role in the assessment of chronic CCP [55]. This is especially true when the echocardiographic examination is nondiagnostic. In settings where the

study may be adequately monitored, dobutamine-stress functional cardiac MRI provides high sensitivity and specificity for ischemia by the induction of wall motion abnormality [56]. However, adenosine-stress cardiac MRI perfusion imaging is easier to perform and also has been shown to have relatively high sensitivity and specificity for the presence of CAD [56-59]. Dipyridamole-stress MRI can also show ischemia-related wall motion abnormalities, perfusion defects and scar and can help direct revascularization [60].

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H. MRA Coronary Arteries

Coronary MRA is a developing modality to evaluate the coronary arteries. Coronary MRA has been shown to identify severe stenosis, but its sensitivity and specificity for moderate or mild lesions is lower [61,62]. Technological developments may make the use of coronary MRA more widespread and result in shorter acquisition times and improved spatial resolution [63].

Variant 1: Chronic chest pain, noncardiac etiology unlikely: low to intermediate probability of coronary artery disease. Initial imaging.
I. Arteriography Coronary

ICA may be used if less-invasive imaging was consistent with the presence of significant CAD. However, the use of ICA as a first-line tool to evaluate for CAD in patients who are low to intermediate probability will not have a high diagnostic yield [64], and utilizing noninvasive testing prior to ICA increases the yield of positive ICA [64].

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J. Exercise Treadmill Testing

Exercise treadmill testing can be of value in the assessment of patients with low to intermediate probability for CAD. Among patients who are low to intermediate probability, exercise treadmill testing in the acute setting showed a high specificity for detecting CAD with a greater than 50% stenosis [65]. This procedure is not included on the variant table because generally only imaging procedures are assessed for appropriateness in the ACR Appropriateness Criteria documents.

Variant 1: Chronic chest pain, noncardiac etiology unlikely: low to intermediate probability of coronary artery disease. Initial imaging.
K. Rb-82 PET/CT Heart

PET/CT performed with perfusion agents (rubidium-82 or nitrogen-13-ammonia) may play a role in assessing patients with chronic indeterminate chest pain and who are at low probability to intermediate probability for CAD. Cardiac PET/CT has been shown to provide incremental prognostic value to historical and clinical variables [66], and may be of particular use in patients with equivocal or suboptimal SPECT MPI or echocardiographic results. Compared to SPECT MPI, PET offers higher spatial and contrast resolution and can be used to quantify myocardial blood flow, increasing the specificity of PET compared to SPECT [67].

Summary of Recommendations

- **Variant 1:** In the evaluation of CCP, noncardiac etiology unlikely, low to intermediate probability of CAD, CTA coronary arteries with IV contrast, or US echocardiography transthoracic stress, or MRI heart with function and vasodilator stress perfusion without and

with IV contrast, or Rb-82 PET/CT heart, or SPECT or SPECT/CT MPI rest and stress, or Tc-99m SPECT/CT stress only is usually appropriate. These procedures are equivalent alternatives.

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. 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 https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition
Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit 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 (Disagreement)	5	The individual ratings are too dispersed from the 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
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (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. Ferencik M, Schlett CL, Bamberg F, et al. Comparison of traditional cardiovascular risk models and coronary atherosclerotic plaque as detected by computed tomography for prediction of acute coronary syndrome in patients with acute chest pain. Acad Emerg Med. 19(8):934-42, 2012 Aug.
2. Fernandez-Friera L, Garcia-Alvarez A, Guzman G, Garcia MJ. Coronary CT and the coronary calcium score, the future of ED risk stratification?. [Review]. Curr Cardiol Rev. 8(2):86-97, 2012 May.
3. Bom MJ, Van der Zee PM, Van der Zant FM, Knol RJ, Cornel JH. Independent prognostic value of coronary artery calcium score and coronary computed tomography angiography in an outpatient cohort of low to intermediate risk chest pain patients. Neth Heart J. 2016;24(5):332-342.
4. Gerber TC, Kantor B, McCollough CH. Radiation dose and safety in cardiac computed tomography. Cardiol Clin. 2009;27(4):665-677.
5. Earls JP, Berman EL, Urban BA, et al. Prospectively gated transverse coronary CT angiography versus retrospectively gated helical technique: improved image quality and reduced radiation dose. Radiology. 2008;246(3):742-753.
6. Husmann L, Valenta I, Gaemperli O, et al. Feasibility of low-dose coronary CT angiography: first experience with prospective ECG-gating. Eur Heart J. 2008;29(2):191-197.
7. Stolzmann P, Leschka S, Scheffel H, et al. Dual-source CT in step-and-shoot mode: noninvasive coronary angiography with low radiation dose. Radiology. 2008;249(1):71-80.
8. Leipsic J, Labounty TM, Heilbron B, et al. Estimated radiation dose reduction using adaptive statistical iterative reconstruction in coronary CT angiography: the ERASIR study. AJR Am J Roentgenol. 2010;195(3):655-660.
9. Achenbach S, Marwan M, Ropers D, et al. Coronary computed tomography angiography with a consistent dose below 1 mSv using prospectively electrocardiogram-triggered high-pitch spiral acquisition. Eur Heart J. 2010;31(3):340-346.
10. Desai MY, Schoenhagen P. Noninvasive testing strategies in symptomatic, intermediate-risk CAD patients: a perspective on the "PROMISE" trial and its potential implementation in

clinical practice. Cardiovasc Diagn Ther. 2015;5(2):166-168.

11. Doris M, Newby DE. Coronary CT Angiography as a Diagnostic and Prognostic Tool: Perspectives from the SCOT-HEART Trial. Curr Cardiol Rep. 2016;18(2):18.

12. Genders TS, Petersen SE, Pugliese F, et al. The optimal imaging strategy for patients with stable chest pain: a cost-effectiveness analysis. Annals of Internal Medicine. 162(7):474-84, 2015 Apr 07.Ann Intern Med. 162(7):474-84, 2015 Apr 07.

13. Marwick TH, Cho I, O Hartaigh B, Min JK. Finding the Gatekeeper to the Cardiac Catheterization Laboratory: Coronary CT Angiography or Stress Testing?. [Review]. J Am Coll Cardiol. 65(25):2747-56, 2015 Jun 30.

14. Poon M, Cortegiano M, Abramowicz AJ, et al. Associations between routine coronary computed tomographic angiography and reduced unnecessary hospital admissions, length of stay, recidivism rates, and invasive coronary angiography in the emergency department triage of chest pain. J Am Coll Cardiol. 62(6):543-52, 2013 Aug 06.

15. Williams MC, Hunter A, Shah AS, et al. Use of Coronary Computed Tomographic Angiography to Guide Management of Patients With Coronary Disease. J Am Coll Cardiol. 2016;67(15):1759-1768.

16. Foy AJ, Dhruva SS, Peterson B, Mandrola JM, Morgan DJ, Redberg RF. Coronary Computed Tomography Angiography vs Functional Stress Testing for Patients With Suspected Coronary Artery Disease: A Systematic Review and Meta-analysis. JAMA Intern Med. 2017;177(11):1623-1631.

17. Schulman-Marcus J, Lin FY, Gransar H, et al. Coronary revascularization vs. medical therapy following coronary-computed tomographic angiography in patients with low-, intermediate- and high-risk coronary artery disease: results from the CONFIRM long-term registry. Eur Heart J Cardiovasc Imaging. 2017;18(8):841-848.

18. Fordyce CB, Newby DE, Douglas PS. Diagnostic Strategies for the Evaluation of Chest Pain: Clinical Implications From SCOT-HEART and PROMISE. [Review]. Journal of the American College of Cardiology. 67(7):843-52, 2016 Feb 23.J Am Coll Cardiol. 67(7):843-52, 2016 Feb 23.

19. Thomas DM, Branch KR, Cury RC. PROMISE of Coronary CT Angiography: Precise and Accurate Diagnosis and Prognosis in Coronary Artery Disease. [Review]. South Med J. 109(4):242-7, 2016 Apr.

20. Lubbers M, Dedic A, Coenen A, et al. Calcium imaging and selective computed tomography angiography in comparison to functional testing for suspected coronary artery disease: the multicentre, randomized CRESCENT trial. Eur Heart J. 2016;37(15):1232-1243.

21. Galperin-Aizenberg M, Cook TS, Hollander JE, Litt HI. Cardiac CT angiography in the emergency department. [Review]. AJR Am J Roentgenol. 204(3):463-74, 2015 Mar.

22. 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.

23. Mahler SA, Hiestand BC, Nwanaji-Enwerem J, et al. Reduction in observation unit length of stay with coronary computed tomography angiography depends on time of emergency department presentation. Acad Emerg Med. 20(3):231-9, 2013 Mar.

24. SCOT-HEART investigators.. CT coronary angiography in patients with suspected angina due

to coronary heart disease (SCOT-HEART): an open-label, parallel-group, multicentre trial.[Erratum appears in Lancet. 2015 Jun 13;385(9985):2354; PMID: 26088642]. Lancet. 385(9985):2383-91, 2015 Jun 13.

25. Douglas PS, Hoffmann U, Patel MR, et al. Outcomes of anatomical versus functional testing for coronary artery disease. New England Journal of Medicine. 372(14):1291-300, 2015 Apr 02.N Engl J Med. 372(14):1291-300, 2015 Apr 02.

26. Hoffmann U, Ferencik M, Udelson JE, et al. Prognostic Value of Noninvasive Cardiovascular Testing in Patients With Stable Chest Pain: Insights From the PROMISE Trial (Prospective Multicenter Imaging Study for Evaluation of Chest Pain). Circulation. 135(24):2320-2332, 2017 Jun 13.Circulation. 135(24):2320-2332, 2017 Jun 13.

27. Schlett CL, Banerji D, Siegel E, et al. Prognostic value of CT angiography for major adverse cardiac events in patients with acute chest pain from the emergency department: 2-year outcomes of the ROMICAT trial. JACC Cardiovasc Imaging. 4(5):481-91, 2011 May.

28. McKavanagh P, Lusk L, Ball PA, et al. A comparison of cardiac computerized tomography and exercise stress electrocardiogram test for the investigation of stable chest pain: the clinical results of the CAPP randomized prospective trial. European heart journal cardiovascular Imaging. 16(4):441-8, 2015 Apr.Eur Heart J Cardiovasc Imaging. 16(4):441-8, 2015 Apr.

29. Hadamitzky M, Achenbach S, Al-Mallah M, et al. Optimized prognostic score for coronary computed tomographic angiography: results from the CONFIRM registry (COronary CT Angiography EvaluatioN For Clinical Outcomes: An InteRnational Multicenter Registry). J Am Coll Cardiol. 2013;62(5):468-476.

30. Puchner SB, Liu T, Mayrhofer T, et al. High-risk plaque detected on coronary CT angiography predicts acute coronary syndromes independent of significant stenosis in acute chest pain: results from the ROMICAT-II trial. J Am Coll Cardiol. 64(7):684-92, 2014 Aug 19.

31. Cury RC, Abbara S, Achenbach S, et al. CAD-RADS(TM) Coronary Artery Disease - Reporting and Data System. An expert consensus document of the Society of Cardiovascular Computed Tomography (SCCT), the American College of Radiology (ACR) and the North American Society for Cardiovascular Imaging (NASCI). Endorsed by the American College of Cardiology. Journal of cardiovascular computed tomography. 10(4):269-81, 2016 Jul-Aug.

32. Feuchtner G, Kerber J, Burghard P, et al. The high-risk criteria low-attenuation plaque <60 HU and the napkin-ring sign are the most powerful predictors of MACE: a long-term follow-up study. Eur Heart J Cardiovasc Imaging. 2017;18(7):772-779.

33. 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.

34. Min JK, Leipsic J, Pencina MJ, et al. Diagnostic accuracy of fractional flow reserve from anatomic CT angiography. Jama 2012;308:1237-45.

35. Taylor CA, Fonte TA, Min JK. Computational fluid dynamics applied to cardiac computed tomography for noninvasive quantification of fractional flow reserve: scientific basis. J Am Coll Cardiol 2013;61:2233-41.

36. Zarins CK, Taylor CA, Min JK. Computed fractional flow reserve (FFTCT) derived from coronary CT angiography. J Cardiovasc Transl Res. 2013;6(5):708-714.

37. Zhang JM, Luo T, Huo Y, et al. Area stenosis associated with non-invasive fractional flow reserve obtained from coronary CT images. Conf Proc IEEE Eng Med Biol Soc. 2013:3865-8, 2013.

38. Jensen JM, Botker HE, Mathiassen ON, et al. Computed tomography derived fractional flow reserve testing in stable patients with typical angina pectoris: influence on downstream rate of invasive coronary angiography. Eur Heart J Cardiovasc Imaging. 2017:[E-pub ahead of print].

39. Douglas PS, Pontone G, Hlatky MA, et al. Clinical outcomes of fractional flow reserve by computed tomographic angiography-guided diagnostic strategies vs. usual care in patients with suspected coronary artery disease: the prospective longitudinal trial of FFR(CT): outcome and resource impacts study. Eur Heart J. 2015;36(47):3359-3367.

40. 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.

41. Abbott BG, Abdel-Aziz I, Nagula S, Monico EP, Schriver JA, Wackers FJ. Selective use of single-photon emission computed tomography myocardial perfusion imaging in a chest pain center. Am J Cardiol. 2001;87(12):1351-1355.

42. Einstein AJ, Johnson LL, DeLuca AJ, et al. Radiation dose and prognosis of ultra-low-dose stress-first myocardial perfusion SPECT in patients with chest pain using a high-efficiency camera. J Nucl Med. 56(4):545-51, 2015 Apr.

43. 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.

44. 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.

45. 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.

46. McKavanagh P, Lusk L, Ball PA, et al. A comparison of Diamond Forrester and coronary calcium scores as gatekeepers for investigations of stable chest pain. Int J Cardiovasc Imaging. 29(7):1547-55, 2013 Oct.

47. Nasir K, Clouse M. Role of nonenhanced multidetector CT coronary artery calcium testing in asymptomatic and symptomatic individuals. [Review]. Radiology. 264(3):637-49, 2012 Sep.

48. Kim YJ, Hur J, Lee HJ, et al. Meaning of zero coronary calcium score in symptomatic patients referred for coronary computed tomographic angiography. Eur Heart J Cardiovasc Imaging. 13(9):776-85, 2012 Sep.

49. Staniak HL, Bittencourt MS, Sharovsky R, Bensenor I, Olmos RD, Lotufo PA. Calcium score to evaluate chest pain in the emergency room. Arq Bras Cardiol. 100(1):90-3, 2013 Jan.

50. Villines TC, Carbonaro S, Hulten E. Calcium scoring and chest pain: is it dead on arrival?. J Cardiovasc Comput Tomogr. 5(1):30-4, 2011 Jan-Feb.

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. Metz LD, Beattie M, Hom R, Redberg RF, Grady D, Fleischmann KE. The prognostic value of normal exercise myocardial perfusion imaging and exercise echocardiography: a meta-analysis. J Am Coll Cardiol. 2007;49(2):227-237.

53. Ciampi Q, Rigo F, Grolla E, Picano E, Cortigiani L. Dual imaging stress echocardiography versus computed tomography coronary angiography for risk stratification of patients with chest pain of unknown origin. Cardiovascular Ultrasound. 13:21, 2015 Apr 21.Cardiovasc. ultrasound. 13:21, 2015 Apr 21.

54. Gibbons RJ, Carryer D, Liu H, et al. Use of Echocardiography in Olmsted County Outpatients With Chest Pain and Normal Resting Electrocardiograms Seen at Mayo Clinic Rochester. Mayo Clinic Proceedings. 90(11):1492-8, 2015 Nov.Mayo Clin Proc. 90(11):1492-8, 2015 Nov.

55. Hundley WG, Morgan TM, Neagle CM, Hamilton CA, Rerkpattanapipat P, Link KM. Magnetic resonance imaging determination of cardiac prognosis. Circulation. 2002;106(18):2328-2333.

56. Paetsch I, Jahnke C, Wahl A, et al. Comparison of dobutamine stress magnetic resonance, adenosine stress magnetic resonance, and adenosine stress magnetic resonance perfusion. Circulation. 2004;110(7):835-842.

57. 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.

58. 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.

59. Ingkanisorn WP, Kwong RY, Bohme NS, et al. Prognosis of negative adenosine stress magnetic resonance in patients presenting to an emergency department with chest pain. J Am Coll Cardiol. 2006;47(7):1427-1432.

60. Bodi V, Husser O, Sanchis J, et al. Prognostic implications of dipyridamole cardiac MR imaging: a prospective multicenter registry. Radiology. 262(1):91-100, 2012 Jan.

61. Kim WY, Danias PG, Stuber M, et al. Coronary magnetic resonance angiography for the detection of coronary stenoses. N Engl J Med. 2001 Dec 27;345(26):1863-9.

62. Watanuki A, Yoshino H, Udagawa H, et al. Quantitative evaluation of coronary stenosis by coronary magnetic resonance angiography. Heart Vessels. 2000;15(4):159-166.

63. Dhawan S, Dharmashankar KC, Tak T. Role of magnetic resonance imaging in visualizing coronary arteries. Clin Med Res. 2004;2(3):173-179.

64. Hwang IC, Kim YJ, Kim KH, et al. Diagnostic yield of coronary angiography in patients with acute chest pain: role of noninvasive test. Am J Emerg Med. 32(1):1-6, 2014 Jan.

65. Blankstein R, Ahmed W, Bamberg F, et al. Comparison of exercise treadmill testing with cardiac computed tomography angiography among patients presenting to the emergency

room with chest pain: the Rule Out Myocardial Infarction Using Computer-Assisted Tomography (ROMICAT) study. Circ Cardiovasc Imaging. 5(2):233-42, 2012 Mar.

66. Yoshinaga K, Chow BJ, Williams K, et al. What is the prognostic value of myocardial perfusion imaging using rubidium-82 positron emission tomography? J Am Coll Cardiol. 2006;48(5):1029-1039.

67. Schindler TH, Schelbert HR, Quercioli A, Dilsizian V. Cardiac PET imaging for the detection and monitoring of coronary artery disease and microvascular health. JACC Cardiovasc Imaging. 2010;3(6):623-640.

68. 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.

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