

American College of Radiology ACR Appropriateness Criteria®

Clinical Condition: Acute Chest Pain — Suspected Pulmonary Embolism

Variant 1: Adult.

Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	9	To exclude other causes of acute chest pain. Complementary to other examinations.	☼
CTA chest with contrast	9	Current standard of care for detecting PE.	☼☼☼
Tc-99m V/Q scan lung	8		☼☼☼
US lower extremity with Doppler	7	If chest x-ray is negative and index of suspicion is high.	O
CTA chest with contrast with CT venography lower extremities	6		☼☼☼
Arteriography pulmonary with right heart catheterization	5	If suspicion is high and CTA is inconclusive, or if intervention is needed.	☼☼☼☼
MRA pulmonary arteries without and with contrast	4	If patient is unable to receive iodinated contrast, may be alternative to V/Q scan. See statement regarding contrast in text under “Anticipated Exceptions.”	O
MRA pulmonary arteries without contrast	3		O
US echocardiography transesophageal	2	Limited experience. Has been used for central pulmonary emboli.	O
US echocardiography transthoracic resting	2	To assess for RV strain or failure in the presence of major pulmonary embolism.	O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

Variant 2: Pregnant patient.

Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	9		☼
US lower extremity with Doppler	8		O
CTA chest with contrast	7		☼☼☼
Tc-99m V/Q scan lung	7	Ventilation done only if necessary.	☼☼☼
Arteriography pulmonary with right heart catheterization	4	Rarely indicated. For clarification or catheter-directed intervention.	☼☼☼☼
CTA chest with contrast with CT venography lower extremities	3		☼☼☼
MRA pulmonary arteries without and with contrast	3	May be used as a problem solver or if intervention is planned. Concern for fetal exposure to contrast.	O
MRA pulmonary arteries without contrast	3		O
US echocardiography transesophageal	2		O
US echocardiography transthoracic resting	2		O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			*Relative Radiation Level

ACUTE CHEST PAIN — SUSPECTED PULMONARY EMBOLISM

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Summary of Literature Review

Introduction/Background

Over 290,000 cases of fatal pulmonary thromboembolism (PE) and 230,000 cases of nonfatal PE are estimated to occur in the United States each year [1]. Additional cases may not be diagnosed because symptoms such as chest pain, shortness of breath, tachycardia, etc are nonspecific and may mimic other pulmonary or cardiac conditions. Unsuspected PE continues to be a frequent autopsy finding.

It has been further estimated that over 80% of PE cases are associated with deep vein thrombosis (DVT). It is, therefore, easy to see why PE, for purposes of diagnosis and treatment, is often considered a complication or a consequence of DVT [2]. A concern with this approach is that some cases of PE are due to embolization from other sites, such as pelvic or upper-extremity veins or the right heart, or even from in-situ thrombosis.

Diagnostic efforts in radiology are aimed at: 1) reaching an acceptable level of diagnostic certainty of PE to warrant anticoagulant therapy, using the least invasive tests, and 2) excluding other reasons for the patient's symptoms. Historically, the probability of a patient having PE is arrived at using a Bayesian approach in which the pretest likelihood of the condition (PE), based on clinical and laboratory evidence, is modified by the results of the appropriate radiological procedure(s) in order to estimate a post-test probability of the condition. This approach has evolved over the last decade. Clinical decision trees, most notably the Wells criteria, have been developed and validated. There have also been major technological advances, primarily in computed tomography (CT) and magnetic resonance imaging (MRI). Many clinical studies have evaluated these modalities, and also the use of imaging in conjunction with clinical criteria and serum assay for D-dimer. High-sensitivity D-dimer testing, using an ELISA (enzyme-linked immunosorbent assay), has improved the specificity of the diagnosis of pulmonary embolism, D-dimer levels will be elevated with any significant thrombotic process, so this test is of limited value in pregnant, postoperative, and trauma patients. It is also of limited value in patients determined to be at high risk of PE by validated clinical criteria. In all other settings a negative D-dimer test effectively excludes pulmonary embolism or DVT [3-7].

Chest Radiograph

The posterior anterior and lateral chest radiograph is an important initial study in the evaluation of suspected PE. The chest radiograph may eliminate the need for additional radiographic procedures by revealing an alternate reason for acute symptoms, such as pneumonia or a large effusion [8]. A normal chest radiograph does not exclude PE, and there are no specific findings that are sufficient to confirm PE. A recent chest radiograph is required to allow accurate interpretation of an abnormal radionuclide ventilation/perfusion lung scan [9].

Computed Tomography

Multidetector computed tomography pulmonary angiography (CTPA) is indicated in the evaluation of patients suspected of having a PE. CTPA is now the primary imaging modality for evaluating patients suspected of having acute PE. CTPA has played an increasingly significant role in the diagnosis of PE since the first major clinical study in 1992 by Remy-Jardin et al [10]. Technological advancements in CT — from helical to multidetector —

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have led to improved resolution of the pulmonary arteries, large and small. Numerous studies have examined the accuracy of CTPA compared to ventilation and perfusion (V/Q) imaging and conventional angiography [11-19].

Multiple studies have shown that CTPA is highly sensitive and specific [12,17,19-21]; discrepancies with conventional angiography are mainly at the subsegmental level where even angiographers tend to have poor interobserver agreement. Intraobserver and interobserver variability for CTPA have been shown to be very good to the segmental level, better than with V/Q imaging.

The overall accuracy of CTPA appears to be very high, and is even higher when combined with clinical assessment and serum D-dimer testing. A positive CTPA result, combined with high or intermediate suspicion on clinical assessment, has a high positive predictive value. In patients with low clinical suspicion and a negative CTPA, acute PE can safely be ruled out. In addition, the adjunctive use of CT venography with CTPA improves the sensitivity of detecting DVT, with similar specificity, thereby increasing the overall accuracy of the diagnosis of thromboembolic disease, as compared to an isolated diagnosis of PE [20-22].

CTPA also has fewer “nondiagnostic” studies than V/Q scans. The false negative rate of CTPA is very low. Outcome studies have shown no adverse outcomes in patients with a negative CTPA who were not subsequently treated. Another study has shown CTPA to be cost-effective in conjunction with lower-extremity duplex examinations. The combination of multidetector CTPA and high-specificity D-dimer testing has very high positive and negative predictive values [12,22,23]. In addition, CTPA may occasionally demonstrate pathology other than PE that may be responsible for the patient’s symptoms.

CTPA can also identify signs of right ventricular dysfunction that may have prognostic significance or implications for treatment (eg, need for the institution of thrombolytic therapy vs conventional anticoagulation alone). Measurements of right ventricular enlargement and reflux of contrast to the inferior vena cava have been used among other indices to gauge right ventricular dysfunction and predict patient mortality [24-28]. Recent technological advancements such as ECG-gated CT and dual-source CT have allowed accurate evaluation of the pulmonary vasculature, thoracic aorta, and coronary arteries on a single CT study. This so-called “triple rule-out” CT protocol has been shown to be feasible, although it has yet to be proven useful or cost-effective through large-scale clinical trials [29-31]. It is possible that the “triple rule-out” CT will become routine in the evaluation of certain patients with acute chest pain in the future.

In general, the data indicate that multidetector CTPA is more accurate than single-slice CT or other studies, such as V/Q scans. Conventional CT with contrast material (not performed as dedicated CTPA) is generally not indicated in the routine workup of acute chest pain thought to be secondary to acute PE [22,32].

Ventilation and Perfusion Imaging

Since its introduction in the mid-1960s, lung perfusion imaging has been indicated in the workup of patients with suspected PE [8,9,33]. The role of lung perfusion imaging for evaluating suspected PE has considerably diminished with the widespread use of CTPA. Still, a normal pattern of regional perfusion in multiple projections, accompanied by a normal ventilation scan, is widely accepted as indicating that pulmonary emboli are not present and no further workup for PE is necessary. The choice between V/Q scans and CTPA remains somewhat controversial [34]. Both modalities have overall good diagnostic accuracy, and, in the presence of a normal radiograph in a cooperative patient, a strong argument can be made that they are equivalent in diagnosing clinically significant pulmonary emboli.

An abnormal pattern of regional lung perfusion (Q) may suggest the diagnosis of PE, but it is not specific. It requires evaluation of the anatomic basis of the perfusion defect (ie, segmental or not) as well as correlation with other modalities such as ventilation (V) imaging and a recent chest radiograph [35-37]. These studies are performed to differentiate between reduced pulmonary arterial blood flow due to vascular obstruction and secondary reductions in regional blood flow associated with a variety of airways diseases.

A number of schemes based on various V/Q scan patterns have been developed to assign different probabilities for the presence (or absence) of PE [35,37-42]. Generally, V/Q findings are categorized as: “high probability,” “intermediate probability” (not meeting the criterion of either “high” or “low”), “low probability,” “very low probability,” and “normal.” All the probability schemes incorporate the results of a recent chest radiograph. At least one study suggests that using single photon emission computed tomography (SPECT) imaging improves the sensitivity and specificity of V/Q scintigraphy [43].

Ventilation imaging may be performed before or after Tc-99m macroaggregated albumin (MAA) perfusion imaging. Performing a low-dose MAA perfusion scan before the Xe-133 ventilation scan allows the ventilation scan to be obtained in the appropriate projection, rather than the usual posterior projection. Also, a normal perfusion scan can obviate the need to perform the ventilation scan, thus lowering radiation dose to the patient. Results with Tc-99m-labeled microaerosol agents (DTPA, pertechnetate, etc) are comparable to those of studies using inert gases such as xenon or krypton and have the advantage of providing multiple views for regional V/Q comparisons.

Lung scans sometimes may be indicated in pregnant women, in which case the administered dose of the radiopharmaceutical(s) should be reduced by a factor of two or more, with correspondingly longer acquisition times to achieve adequate imaging statistics. Doing so may minimize radiation absorbed dose. If the MAA perfusion scan is performed first and is normal, the ventilation scan can be avoided.

A follow-up MAA perfusion scan may be recommended 6-8 weeks after the discovery of a “mismatched” V/Q pattern (presumption of PE). Failure of observed resolution, or of at least significant improvement in regional perfusion, may signal the development of pulmonary hypertension secondary to chronic thromboembolic obstruction in the major pulmonary vessels. This complication has an expected incidence of less than 1%. Caution should be exercised in interpreting perfusion imaging in the days after acute PE, because reestablishment of regional perfusion (resolution of defects) occurs at varying and unpredictable rates. Conversely, local ventilation may be compromised for minutes to hours after an acute pulmonary embolism.

The modality of choice (CTPA vs V/Q scan) in pregnant patients remains a matter of debate [44,45]. The maternal breast dose is clearly higher with CTPA, but whether or not the fetal dose is different remains unclear. Studies suggest that if the chest radiograph is normal, a perfusion scan alone may be satisfactory [46]. Conversely, dose-lowering techniques may make the absorbed dose lower with CT.

MAA Perfusion Imaging Without Ventilation Imaging

MAA perfusion imaging without ventilation may be indicated particularly when the condition of the patient suddenly deteriorates and acute PE is suspected as a significant contributing cause. A demonstration of regions of reduced perfusion, not explained by recent chest radiograph findings, warrants a consideration of PE and possibly the need for further workup such as pulmonary angiography. It may also be indicated in patients who are not candidates for MDCTA, such as those who are too large to fit into CT gantries, who are unable to remain still and hold their breath for the few seconds necessary, or who have severe renal impairment.

Catheter-Directed Selective Pulmonary Angiography

Pulmonary angiography, including right heart catheterization and measurement of pulmonary artery and right heart pressures, is an acceptably safe, albeit invasive, procedure when performed by an experienced operator with adequate patient monitoring. The results may establish the specific diagnosis of PE when an acceptable level of certainty cannot be reached by noninvasive imaging [38,47,48]. Given the accuracy of CTPA, however, unacceptably low levels of certainty are increasingly rare. Further, the experience of the radiologist who performs and interprets this invasive procedure is crucial. As indicated, studies suggest that the overall accuracy of catheter pulmonary angiography may be inferior to that of multidetector CTPA, due to technical factors such as patient movement and vessel overlap, as well as inter- and intra-observer variability in interpretation.

The amount of contrast material injected should be limited to that necessary to establish (or exclude) the presence of PE. The number of selective arterial injections may be reduced by focusing on suspicious pulmonary vascular territories indicated by the results of noninvasive V/Q lung scanning. Magnification techniques and imaging in special projections may overcome problems with overlapping vessels.

The general indications for pulmonary angiography in the past have included a) cases with “low probability” or “intermediate probability” V/Q scan findings, particularly when there is a high clinical suspicion for PE, and anticoagulation is considered risky or relatively contraindicated; b) circumstances where a specific diagnosis of PE is considered necessary for the proper management of the patient; c) when pulmonary thromboendarterectomy or thrombolysis is considered (eg, chronic pulmonary hypertension secondary to major vessel thromboembolic occlusion or symptomatic massive or submassive PE that may require catheter-directed therapy); and d) before placement of an inferior vena cava (IVC) filter. Because multidetector CTPA is currently the standard of care for PE detection, there are now far fewer cases in which catheter pulmonary angiography is indicated or necessary, and these are now largely confined to situations in which catheter-directed thrombectomy or thrombolysis is thought to be clinically indicated.

Ultrasound

Transthoracic echo (TTE) and transesophageal echo (TEE) studies are generally not indicated in the diagnosis of acute PE in the setting of acute chest pain [49]. However, these ultrasound (US) procedures are useful in evaluating right ventricular morphology and function that in turn have prognostic implications for morbidity, mortality, and development of future venous thromboembolism [50-55].

Because of the high association of DVT with PE, US evaluation of the venous drainage of the lower extremities is probably indicated. US studies include duplex Doppler with leg compression and continuous-wave Doppler [56,57]. The presence of DVT does not indicate the presence (or absence) of PE, but may increase (or decrease) its likelihood. Also, positive DVT studies may identify patients at higher risk for subsequent PE. In most patients, however, the presence of DVT — whether or not associated with PE — has identical treatment, so no further diagnostic evaluation for PE is needed. A negative extremity US study does not exclude PE, although it significantly decreases its likelihood [58-60]. For a more detailed discussion on DVT, refer to the ACR Appropriateness Criteria® on “[Suspected Lower Extremity Deep Vein Thrombosis](#).”

Magnetic Resonance Angiography, Magnetic Resonance Imaging, and Perfusion Imaging

Magnetic resonance angiography (MRA) and MR perfusion imaging can provide rapid, noninvasive evaluation of the central and segmental pulmonary arteries [61-64]. MR perfusion imaging has high sensitivity for PE and is most useful when combined with magnetic resonance imaging (MRI) and MRA [61]. Technologic innovations and increased experience may increase the role of MRA and MR perfusion imaging. Currently, MR is mainly used at institutions with particular interest in and expertise and experience with these techniques. It is also of at least theoretical value in pregnant patients, as well as patients in whom the use of iodinated contrast agents is contraindicated [65]. While there are no studies to date suggesting that there is risk to a developing fetus, there is also no proof that the use of gadolinium-containing contrast agents is safe. They should, therefore, be used only when clearly indicated.

MRI without MRA is probably not indicated in the routine evaluation of patients with suspected PE. It may rarely be useful in patients who have large central emboli, particularly if used in conjunction with MRI for other indications, such as cardiac morphologic evaluation [66,67].

Summary

- PE remains a common and important condition.
- A chest radiograph cannot exclude or confirm PE, but is important (as a complementary study) as it can guide further investigations and suggest alternative diagnoses.
- In general, any test that can confirm either DVT (ie, lower-extremity venous duplex) or PE is sufficient. Only certain studies, however, have sufficient accuracy to exclude PE.
- Multislice CT pulmonary angiography is the current standard of care to confirm or exclude PE.
- V/Q scanning appears to also have high overall accuracy.
- In pregnancy, with radiation a particular concern, the choice between perfusion scanning and CTPA depends on local equipment and expertise as well as patient factors (normal chest radiograph, ability to breathhold).

Safety Considerations in Pregnant Patients

Imaging of the pregnant patient can be challenging, particularly with respect to minimizing radiation exposure and risk. For further information and guidance, see the following ACR documents:

- [ACR Practice Guideline for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation](#)
- [ACR-ACOG-AIUM Practice Guideline for the Performance of Obstetrical Ultrasound](#)
- [ACR Manual on Contrast Media](#)
- [ACR Guidance Document for Safe MR Practices](#)

Anticipated Exceptions

If multidetector CTPA is not available, then V/Q scans, pulmonary MRA and/or lower extremity ultrasound may need to be used for evaluation. The choice between CTPA and V/Q scanning in pregnant patients remains unresolved. With careful, modern techniques, both are acceptable. The radiation dose to the fetus, in general, is probably lower with V/Q scanning, although dose modulation techniques with CT may make the two modalities

nearly equivalent in absorbed dose. If a chest radiograph is abnormal, CTPA has a higher likelihood of being definitive [46].

Nephrogenic systemic fibrosis (NSF) is a disorder with a scleroderma-like presentation and a spectrum of manifestations that can range from limited clinical sequelae to fatality. It appears to be related to both underlying severe renal dysfunction and the administration of gadolinium-based contrast agents. It has occurred primarily in patients on dialysis, rarely in patients with very limited glomerular filtration rate (GFR) (ie, <30 mL/min/1.73m²), and almost never in other patients. There is growing literature regarding NSF. Although some controversy and lack of clarity remain, there is a consensus that it is advisable to avoid all gadolinium-based contrast agents in dialysis-dependent patients unless the possible benefits clearly outweigh the risk, and to limit the type and amount in patients with estimated GFR rates <30 mL/min/1.73m². For more information, please see the [ACR Manual on Contrast Media](#) [68].

Relative Radiation Level Information

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

Relative Radiation Level Designations		
Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
⊕	<0.1 mSv	<0.03 mSv
⊕⊕	0.1-1 mSv	0.03-0.3 mSv
⊕⊕⊕	1-10 mSv	0.3- 3 mSv
⊕⊕⊕⊕	10-30 mSv	3-10 mSv
⊕⊕⊕⊕⊕	30-100 mSv	10-30 mSv
*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (eg, region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as “Varies”.		

Supporting Documents

- [ACR Appropriateness Criteria® Overview](#)
- [Procedure Information](#)
- [Evidence Table](#)

References

1. Heit JA, Cohen AT, Anderson FA, Jr., on Behalf of the VTE Impact Assessment Group. Estimated Annual Number of Incident and Recurrent, Non-Fatal and Fatal Venous Thromboembolism (VTE) Events in the US. *ASH Annual Meeting Abstracts*. 2005;106(11):910.
2. Stein PD, Hull RD, Saltzman HA, Pineo G. Strategy for diagnosis of patients with suspected acute pulmonary embolism. *Chest*. 1993;103(5):1553-1559.
3. Agnelli G, Becattini C. Acute pulmonary embolism. *N Engl J Med*. 2010;363(3):266-274.

4. Gandara E, Wells PS. Diagnosis: use of clinical probability algorithms. *Clin Chest Med*. 2010;31(4):629-639.
5. Gimber LH, Travis RI, Takahashi JM, Goodman TL, Yoon HC. Computed Tomography Angiography in Patients Evaluated for Acute Pulmonary Embolism with Low Serum D-dimer Levels: A Prospective Study. *Perm J*. 2009;13(4):4-10.
6. Gupta RT, Kakarla RK, Kirshenbaum KJ, Tapson VF. D-dimers and efficacy of clinical risk estimation algorithms: sensitivity in evaluation of acute pulmonary embolism. *AJR Am J Roentgenol*. 2009;193(2):425-430.
7. Kabrhel C. Outcomes of high pretest probability patients undergoing d-dimer testing for pulmonary embolism: a pilot study. *J Emerg Med*. 2008;35(4):373-377.
8. Greenspan RH, Ravin CE, Polansky SM, McLoud TC. Accuracy of the chest radiograph in diagnosis of pulmonary embolism. *Invest Radiol*. 1982;17(6):539-543.
9. Worsley DF, Alavi A, Aronchick JM, Chen JT, Greenspan RH, Ravin CE. Chest radiographic findings in patients with acute pulmonary embolism: observations from the PIOPED Study. *Radiology*. 1993;189(1):133-136.
10. Remy-Jardin M, Remy J, Wattinne L, Giraud F. Central pulmonary thromboembolism: diagnosis with spiral volumetric CT with the single-breath-hold technique--comparison with pulmonary angiography. *Radiology*. 1992;185(2):381-387.
11. Blachere H, Latrabe V, Montaudon M, et al. Pulmonary embolism revealed on helical CT angiography: comparison with ventilation-perfusion radionuclide lung scanning. *AJR Am J Roentgenol*. 2000;174(4):1041-1047.
12. Coche E, Verschuren F, Keyeux A, et al. Diagnosis of acute pulmonary embolism in outpatients: comparison of thin-collimation multi-detector row spiral CT and planar ventilation-perfusion scintigraphy. *Radiology*. 2003;229(3):757-765.
13. Cross JJ, Kemp PM, Walsh CG, Flower CD, Dixon AK. A randomized trial of spiral CT and ventilation perfusion scintigraphy for the diagnosis of pulmonary embolism. *Clin Radiol*. 1998;53(3):177-182.
14. Ferretti GR, Bosson JL, Buffaz PD, et al. Acute pulmonary embolism: role of helical CT in 164 patients with intermediate probability at ventilation-perfusion scintigraphy and normal results at duplex US of the legs. *Radiology*. 1997;205(2):453-458.
15. Garg K, Welsh CH, Feyerabend AJ, et al. Pulmonary embolism: diagnosis with spiral CT and ventilation-perfusion scanning--correlation with pulmonary angiographic results or clinical outcome. *Radiology*. 1998;208(1):201-208.
16. Gerard SK, Hsu TC. Pulmonary embolism: diagnosis with spiral CT versus ventilation-perfusion scintigraphy. *Radiology*. 1999;210(2):576-577.
17. Katsouda E, Mystakidou K, Rapti A, et al. Evaluation of spiral computed tomography versus ventilation/perfusion scanning in patients clinically suspected of pulmonary embolism. *In Vivo*. 2005;19(5):873-878.
18. Mayo JR, Remy-Jardin M, Muller NL, et al. Pulmonary embolism: prospective comparison of spiral CT with ventilation-perfusion scintigraphy. *Radiology*. 1997;205(2):447-452.
19. Hiorns MP, Mayo JR. Spiral computed tomography for acute pulmonary embolism. *Can Assoc Radiol J*. 2002;53(5):258-268.
20. Stein PD, Fowler SE, Goodman LR, et al. Multidetector computed tomography for acute pulmonary embolism. *N Engl J Med*. 2006;354(22):2317-2327.
21. van Rossum AB, Pattynama PM, Mallens WM, Hermans J, Heijerman HG. Can helical CT replace scintigraphy in the diagnostic process in suspected pulmonary embolism? A retrospective-prospective cohort study focusing on total diagnostic yield. *Eur Radiol*. 1998;8(1):90-96.
22. Schoepf UJ, Costello P. CT angiography for diagnosis of pulmonary embolism: state of the art. *Radiology*. 2004;230(2):329-337.
23. Hirai LK, Takahashi JM, Yoon HC. A prospective evaluation of a quantitative D-dimer assay in the evaluation of acute pulmonary embolism. *J Vasc Interv Radiol*. 2007;18(8):970-974.
24. Ghuyssen A, Ghaye B, Willems V, et al. Computed tomographic pulmonary angiography and prognostic significance in patients with acute pulmonary embolism. *Thorax*. 2005;60(11):956-961.
25. He H, Stein MW, Zalta B, Haramati LB. Computed tomography evaluation of right heart dysfunction in patients with acute pulmonary embolism. *J Comput Assist Tomogr*. 2006;30(2):262-266.
26. Lu MT, Cai T, Ersoy H, et al. Interval increase in right-left ventricular diameter ratios at CT as a predictor of 30-day mortality after acute pulmonary embolism: initial experience. *Radiology*. 2008;246(1):281-287.

27. Nural MS, Elmali M, Findik S, et al. Computed tomographic pulmonary angiography in the assessment of severity of acute pulmonary embolism and right ventricular dysfunction. *Acta Radiol.* 2009;50(6):629-637.
28. van der Meer RW, Pattynama PM, van Strijen MJ, et al. Right ventricular dysfunction and pulmonary obstruction index at helical CT: prediction of clinical outcome during 3-month follow-up in patients with acute pulmonary embolism. *Radiology.* 2005;235(3):798-803.
29. Haidary A, Bis K, Vrachliotis T, Kosuri R, Balasubramaniam M. Enhancement performance of a 64-slice triple rule-out protocol vs 16-slice and 10-slice multidetector CT-angiography protocols for evaluation of aortic and pulmonary vasculature. *J Comput Assist Tomogr.* 2007;31(6):917-923.
30. Johnson TR, Nikolaou K, Wintersperger BJ, et al. ECG-gated 64-MDCT angiography in the differential diagnosis of acute chest pain. *AJR Am J Roentgenol.* 2007;188(1):76-82.
31. Schertler T, Frauenfelder T, Stolzmann P, et al. Triple rule-out CT in patients with suspicion of acute pulmonary embolism: findings and accuracy. *Acad Radiol.* 2009;16(6):708-717.
32. Chintapalli K, Thorsen MK, Olson DL, Goodman LR, Gurney J. Computed tomography of pulmonary thromboembolism and infarction. *J Comput Assist Tomogr.* 1988;12(4):553-559.
33. Wagner HN, Jr., Sabiston DC, Jr., Iio M, McAfee JG, Meyer JK, Langan JK. Regional Pulmonary Blood Flow In Man By Radioisotope Scanning. *Jama.* 1964;187:601-603.
34. Anderson DR, Kahn SR, Rodger MA, et al. Computed tomographic pulmonary angiography vs ventilation-perfusion lung scanning in patients with suspected pulmonary embolism: a randomized controlled trial. *Jama.* 2007;298(23):2743-2753.
35. Biello DR, Mattar AG, McKnight RC, Siegel BA. Ventilation-perfusion studies in suspected pulmonary embolism. *AJR Am J Roentgenol.* 1979;133(6):1033-1037.
36. Hull RD, Hirsh J, Carter CJ, et al. Diagnostic value of ventilation-perfusion lung scanning in patients with suspected pulmonary embolism. *Chest.* 1985;88(6):819-828.
37. Stein PD, Henry JW, Gottschalk A. Mismatched vascular defects. An easy alternative to mismatched segmental equivalent defects for the interpretation of ventilation/perfusion lung scans in pulmonary embolism. *Chest.* 1993;104(5):1468-1471.
38. Value of the ventilation/perfusion scan in acute pulmonary embolism. Results of the prospective investigation of pulmonary embolism diagnosis (PIOPED). The PIOPED Investigators. *Jama.* 1990;263(20):2753-2759.
39. Gottschalk A, Sostman HD, Coleman RE, et al. Ventilation-perfusion scintigraphy in the PIOPED study. Part II. Evaluation of the scintigraphic criteria and interpretations. *J Nucl Med.* 1993;34(7):1119-1126.
40. Sostman HD, Coleman RE, DeLong DM, Newman GE, Paine S. Evaluation of revised criteria for ventilation-perfusion scintigraphy in patients with suspected pulmonary embolism. *Radiology.* 1994;193(1):103-107.
41. Webber MM, Gomes AS, Roe D, La Fontaine RL, Hawkins RA. Comparison of Biello, McNeil, and PIOPED criteria for the diagnosis of pulmonary emboli on lung scans. *AJR Am J Roentgenol.* 1990;154(5):975-981.
42. Gottschalk A, Stein PD, Sostman HD, Matta F, Beemath A. Very low probability interpretation of V/Q lung scans in combination with low probability objective clinical assessment reliably excludes pulmonary embolism: data from PIOPED II. *J Nucl Med.* 2007;48(9):1411-1415.
43. Reinartz P, Wildberger JE, Schaefer W, Nowak B, Mahnken AH, Buell U. Tomographic imaging in the diagnosis of pulmonary embolism: a comparison between V/Q lung scintigraphy in SPECT technique and multislice spiral CT. *J Nucl Med.* 2004;45(9):1501-1508.
44. Revel MP, Cohen S, Sanchez O, et al. Pulmonary Embolism during Pregnancy: Diagnosis with Lung Scintigraphy or CT Angiography? *Radiology.* 2011;258(2):590-598.
45. Shahir K, Goodman LR, Tali A, Thorsen KM, Hellman RS. Pulmonary embolism in pregnancy: CT pulmonary angiography versus perfusion scanning. *AJR Am J Roentgenol.* 2010;195(3):W214-220.
46. Cahill AG, Stout MJ, Macones GA, Bhalla S. Diagnosing pulmonary embolism in pregnancy using computed-tomographic angiography or ventilation-perfusion. *Obstet Gynecol.* 2009;114(1):124-129.
47. Cheely R, McCartney WH, Perry JR, et al. The role of noninvasive tests versus pulmonary angiography in the diagnosis of pulmonary embolism. *Am J Med.* 1981;70(1):17-22.
48. Hull RD, Hirsh J, Carter CJ, et al. Pulmonary angiography, ventilation lung scanning, and venography for clinically suspected pulmonary embolism with abnormal perfusion lung scan. *Ann Intern Med.* 1983;98(6):891-899.
49. Hirohashi T, Yoshinaga K, Sakurai T, et al. [Study of the echocardiographic diagnosis of acute pulmonary thromboembolism and risk factors for venous thromboembolism]. *J Cardiol.* 2006;47(2):63-71.
50. Grifoni S, Vanni S, Magazzini S, et al. Association of persistent right ventricular dysfunction at hospital discharge after acute pulmonary embolism with recurrent thromboembolic events. *Arch Intern Med.* 2006;166(19):2151-2156.

51. Kjaergaard J, Schaadt BK, Lund JO, Hassager C. Quantitative measures of right ventricular dysfunction by echocardiography in the diagnosis of acute nonmassive pulmonary embolism. *J Am Soc Echocardiogr.* 2006;19(10):1264-1271.
52. Lechleitner P, Riedl B, Raneburger W, Gamper G, Theurl A, Lederer A. Chest sonography in the diagnosis of pulmonary embolism: a comparison with MRI angiography and ventilation perfusion scintigraphy. *Ultraschall Med.* 2002;23(6):373-378.
53. Mathis G, Bitschnau R, Gehmacher O, et al. Chest ultrasound in diagnosis of pulmonary embolism in comparison to helical CT. *Ultraschall Med.* 1999;20(2):54-59.
54. Patel JJ, Chandrasekaran K, Maniet AR, Ross JJ, Jr., Weiss RL, Guidotti JA. Impact of the incidental diagnosis of clinically unsuspected central pulmonary artery thromboembolism in treatment of critically ill patients. *Chest.* 1994;105(4):986-990.
55. Toosi MS, Merlino JD, Leeper KV. Prognostic value of the shock index along with transthoracic echocardiography in risk stratification of patients with acute pulmonary embolism. *Am J Cardiol.* 2008;101(5):700-705.
56. Beecham RP, Dorfman GS, Cronan JJ, Spearman MP, Murphy TP, Scola FH. Is bilateral lower extremity compression sonography useful and cost-effective in the evaluation of suspected pulmonary embolism? *AJR Am J Roentgenol.* 1993;161(6):1289-1292.
57. Cronan JJ, Dorfman GS, Scola FH, Schepps B, Alexander J. Deep venous thrombosis: US assessment using vein compression. *Radiology.* 1987;162(1 Pt 1):191-194.
58. Quinn RJ, Nour R, Butler SP, et al. Pulmonary embolism in patients with intermediate probability lung scans: diagnosis with Doppler venous US and D-dimer measurement. *Radiology.* 1994;190(2):509-511.
59. Smith LL, Iber C, Sirr S. Pulmonary embolism: confirmation with venous duplex US as adjunct to lung scanning. *Radiology.* 1994;191(1):143-147.
60. Sumner DS, Lambeth A. Reliability of Doppler ultrasound in the diagnosis of acute venous thrombosis both above and below the knee. *Am J Surg.* 1979;138(2):205-210.
61. Kluge A, Luboldt W, Bachmann G. Acute pulmonary embolism to the subsegmental level: diagnostic accuracy of three MRI techniques compared with 16-MDCT. *AJR Am J Roentgenol.* 2006;187(1):W7-14.
62. Kluge A, Mueller C, Strunk J, Lange U, Bachmann G. Experience in 207 combined MRI examinations for acute pulmonary embolism and deep vein thrombosis. *AJR Am J Roentgenol.* 2006;186(6):1686-1696.
63. Oudkerk M, van Beek EJ, Wielopolski P, et al. Comparison of contrast-enhanced magnetic resonance angiography and conventional pulmonary angiography for the diagnosis of pulmonary embolism: a prospective study. *Lancet.* 2002;359(9318):1643-1647.
64. Pleszewski B, Chartrand-Lefebvre C, Qanadli SD, et al. Gadolinium-enhanced pulmonary magnetic resonance angiography in the diagnosis of acute pulmonary embolism: a prospective study on 48 patients. *Clin Imaging.* 2006;30(3):166-172.
65. Chen MM, Coakley FV, Kaimal A, Laros RK, Jr. Guidelines for computed tomography and magnetic resonance imaging use during pregnancy and lactation. *Obstet Gynecol.* 2008;112(2 Pt 1):333-340.
66. Erdman WA, Peshock RM, Redman HC, et al. Pulmonary embolism: comparison of MR images with radionuclide and angiographic studies. *Radiology.* 1994;190(2):499-508.
67. Kluge A, Muller C, Hansel J, Gerriets T, Bachmann G. Real-time MR with TrueFISP for the detection of acute pulmonary embolism: initial clinical experience. *Eur Radiol.* 2004;14(4):709-718.
68. American College of Radiology. *Manual on Contrast Media.* Available at: http://www.acr.org/SecondaryMainMenuCategories/quality_safety/contrast_manual.aspx.

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