American College of Radiology
ACR Appropriateness Criteria®
Suspected Pulmonary Embolism

Variant 1: **Suspected pulmonary embolism. Intermediate probability with a negative D-dimer or low pretest probability.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	9		☢
CTA chest with IV contrast	5	This procedure should be optimized for pulmonary arterial enhancement. This procedure may be appropriate but there was disagreement among panel members on the appropriateness rating as defined by the panel's median rating.	☢☢☢
CT chest with IV contrast	3	This procedure should be optimized for pulmonary arterial enhancement.	☢☢☢
US duplex Doppler lower extremity	3	This procedure has a low yield in the absence of symptoms of DVT.	O
CT chest without IV contrast	2		☢☢☢
Tc-99m V/Q scan lung	2		☢☢☢
CTA chest with IV contrast with CT venography lower extremities	2		☢☢☢
MRA chest without and with IV contrast	2		O
US echocardiography transthoracic resting	2		O
CT chest without and with IV contrast	1		☢☢☢
Arteriography pulmonary with right heart catheterization	1		☢☢☢☢
MRA chest without IV contrast	1		O
US echocardiography transesophageal	1		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: **Suspected pulmonary embolism. Intermediate probability with a positive D-dimer or high pretest probability.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	9		☢
CTA chest with IV contrast	9	This procedure should be optimized for pulmonary circulation.	☢☢☢
CT chest with IV contrast	9	This procedure should be optimized for pulmonary circulation. This procedure may be an alternative to CTA, but both should not be performed.	☢☢☢
Tc-99m V/Q scan lung	7	This procedure may be an alternative to CTA, but both should not be performed.	☢☢☢
US duplex Doppler lower extremity	7	This procedure may be an initial study prior to CTA.	O
MRA chest without and with IV contrast	6		O
CTA chest with IV contrast with CT venography lower extremities	5		☢☢☢
Arteriography pulmonary with right heart catheterization	3		☢☢☢☢
US echocardiography transthoracic resting	3		O
CT chest without IV contrast	2		☢☢☢
CT chest without and with IV contrast	2		☢☢☢
MRA chest without IV contrast	2	This procedure has limited sensitivity and may be indicated for rare situations or certain contraindications for a specific patient.	O
US echocardiography transesophageal	2		O
Rating Scale: 1,2,3 Usually not appropriate; 4,5,6 May be appropriate; 7,8,9 Usually appropriate			***Relative Radiation Level**

Variant 3: **Suspected pulmonary embolism. Pregnant patient.**

Radiologic Procedure	Rating	Comments	RRL*
X-ray chest	9		☢
US duplex Doppler lower extremity	8	This procedure may be an initial examination prior to CTA, which may prevent the need for ionizing radiation in the appropriate clinical setting.	O
CTA chest with IV contrast	7	This procedure should be optimized for pulmonary circulation.	☢☢☢
CT chest with IV contrast	7	This procedure should be optimized for pulmonary circulation. This procedure may be an alternative to CTA, but both should not be performed.	☢☢☢
Tc-99m V/Q scan lung	7	This procedure may be an alternative to CTA, but both should not be performed. Ventilation should be done only if necessary.	☢☢☢
Arteriography pulmonary with right heart catheterization	4	This procedure is rarely indicated. It is used for clarification or catheter-directed intervention.	☢☢☢☢
CTA chest with IV contrast with CT venography lower extremities	3		☢☢☢
MRA chest without and with IV contrast	3	This procedure may be used as a problem solver or if intervention is planned. There is concern for fetal exposure to contrast.	O
MRA chest without IV contrast	3		O
CT chest without IV contrast	2		☢☢☢
CT chest without and with IV contrast	2		☢☢☢
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**

SUSPECTED PULMONARY EMBOLISM

Expert Panels on Cardiac and Thoracic Imaging: Jacobo Kirsch, MD [1]; Richard K. J. Brown, MD[2]; Travis S. Henry, MD[3]; Cylen Javidan-Nejad, MD[4]; Clinton Jokerst, MD[5]; Paul R. Julsrud, MD[6]; Jeffrey P. Kanne, MD[7]; Christopher M. Kramer, MD[8]; Jonathon A. Leipsic, MD[9]; Kalpesh K. Panchal, MD[10]; James G. Ravenel, MD[11]; Amar B. Shah, MD[12]; Tan-Lucien H. Mohammed, MD[13]; Pamela K. Woodard, MD[14]; Suhny Abbara, MD.[15]

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, and tachycardia 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.

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 the use of imaging in conjunction with clinical criteria and serum assay for D-dimer. High-sensitivity D-dimer testing using an enzyme-linked immunosorbent assay has improved the specificity of the diagnosis of PE. 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 PE or DVT [3-7].

Overview of Imaging Modalities

Chest Radiography

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 (V/Q) lung scan [9].

Computed Tomography

Multidetector CT 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—have led to improved

[1]Principal Author, Cleveland Clinic, Weston, Florida. [2]University Hospital, Ann Arbor, Michigan. [3]University of California San Francisco, San Francisco, California. [4]Mallinckrodt Institute of Radiology, Washington University School of Medicine, Saint Louis, Missouri. [5]Banner University Medical Center, Tucson, Arizona. [6]Mayo Clinic, Rochester, Minnesota. [7]University of Wisconsin School of Medicine and Public Health, Madison, Wisconsin. [8]University of Virginia Health System, Charlottesville, Virginia, American College of Cardiology. [9]St. Paul's Hospital, Vancouver, British Columbia, Canada. [10]University of Cincinnati Hospital, Cincinnati, Ohio. [11]Medical University of South Carolina, Charleston, South Carolina. [12]Westchester Medical Center, Valhalla, New York. [13]Specialty Chair, University of Florida College of Medicine, Gainesville, Florida. [14]Specialty Chair, Mallinckrodt Institute of Radiology, Washington University School of Medicine, Saint Louis, Missouri. [15]Panel Chair, UT Southwestern Medical Center, Dallas, Texas.

resolution of the pulmonary arteries, large and small. Numerous studies have examined the accuracy of CTPA compared to V/Q imaging and conventional angiography [11-19]. Although 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, it should be acknowledged that incidental PE can be accurately diagnosed on routine chest CT with contrast [20,21].

It is important to recognize that the increased sensitivity of CT has raised concerns related to evidence of substantial increase in complications from anticoagulation due to the overdiagnosis of PE. However, studies are needed to better determine which small emboli may benefit from treatment and which can go untreated [22,23].

For the purposes of distinguishing between CT and CT angiography (CTA), American College of Radiology (ACR) Appropriateness Criteria topics use the definition in the Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography (CTA) [24]:

> "C*TA 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 3D renderings."*

All elements are essential: 1) timing, 2) reconstructions/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 the Centers for Medicare & Medicaid Services has applied to the Current Procedural Terminology codes.

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]. 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.

An abnormal pattern of regional lung perfusion 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 imaging and a recent chest radiograph [25,26]. 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 airway diseases [25-36].

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 [26,27,29,30,35,36]. 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 1 study suggests that using single-photon emission CT (SPECT) imaging improves the sensitivity and specificity of V/Q scintigraphy [34].

Ventilation imaging can 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. In addition, 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 (diethylenetriamine pentaacetic acid, 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.

Macroaggregated Albumin 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 multidetector CTA, 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 [27,28,33]. 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 intraobserver 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 can 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.

Ultrasound

Transthoracic echocardiogram and transesophageal echocardiogram studies are generally not indicated in the diagnosis of acute PE in the setting of acute chest pain [32]. 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 [31,37-41].

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 [42-45]. Current MRI technology demonstrates high specificity and high sensitivity for proximal PE but still limited sensitivity for distal PE and 30% of inconclusive results [46]. The PIOPED III (Prospective Investigation of Pulmonary Embolism Diagnosis III) Trial was a multicenter study designed to assess the sensitivity and specificity of MRA, alone or with magnetic resonance venography, for diagnosing PE and venous thromboembolism. It showed that technically adequate MRA had a sensitivity of 78% and a specificity of 99% and that technically adequate MRA and venography had a sensitivity of 92% and a specificity of 96%. It is important to note that the study had a high number of technically inadequate results (up to 52% of patients in the MRA and venography group) and that this varied significantly by clinical center. Due to these findings, the investigators recommended MRA to be considered only at centers that routinely perform it well and only for patients for whom standard tests are contraindicated [47,48]. A recent study from Schiebler et al [49] demonstrated that pulmonary MRA studies reach a negative predictive value of up to 97% in patients when followed up clinically for evidence of venous thromboembolism. Just as important, they report 95% of their studies to be of diagnostic quality.

MR perfusion imaging has high sensitivity for PE and is most useful when combined with MRI and MRA [42].

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 [50,51].

Discussion of the Imaging Modalities by Variant

Variant 1: Suspected pulmonary embolism. Intermediate probability with a negative D-dimer or low pretest probability.

In hemodynamically stable patients with a low or intermediate clinical probability of PE, normal results on D-dimer testing avoid unnecessary further investigation. In such patients, if anticoagulant treatment is not given, the estimated 3-month risk of thromboembolism is 0.14% (95% confidence interval, 0.05–0.41) [3].

In 2011, the National Quality Forum (NQF) endorsed an imaging efficiency measure directed at the appropriateness of CTPA use in emergency department patients. According to NQF measures, imaging was avoidable in 32% of patients, with failure to perform D-dimer testing responsible for nearly two-thirds of potentially avoidable imaging studies [52]. A meta-analysis of 52 studies, comprising 55,268 patients, comparing the test characteristics of gestalt (a physician's unstructured estimate) and clinical decision rules for evaluating adults with suspected PE showed that PE can be safely excluded by a low clinical probability assessment and a negative D-dimer result without the need of imaging [53].

The PIOPED investigators reported that the combination of a low-probability V/Q scan result and low clinical suspicion reduced the likelihood of PE to <5%. This observation suggests that excluding PE in patients with minimal scan abnormalities and low clinical suspicion for this disorder may be reasonable [54].

The intermediate pretest probability subgroup may present a more challenging diagnostic enigma. For these patients D-dimer testing is warranted [55]. Recent studies have demonstrated that a normal high-sensitivity D-dimer level can be used to further risk-stratify patients at both low and intermediate risk for PE. Perrier et al [56] enrolled 674 non–high-risk patients (at either low or intermediate risk for PE). Those with normal D-dimer levels were followed for 3 months and no thromboembolic events were noted [55,56]. Warren et al [57] used the Wells criteria, and Gupta et al [6] used the revised Geneva score. They evaluated 1679 and 330 patients, respectively, who were determined to be at intermediate risk for PE and found that a normal D-dimer level was 99.5% and 100% sensitive, respectively for excluding PE on CT [6,55,57]. A negative result from a high-sensitivity D-dimer test in patients with either low or intermediate probability safely excludes PE without the need for further imaging.

Variant 2: Suspected pulmonary embolism. Intermediate probability with a positive D-dimer or high pretest probability.

Multiple studies have shown that CTPA is highly sensitive and specific [12,17,18,58,59]; 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 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 [20,58,59].

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 [12,20,60]. 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 versus conventional anticoagulation alone). Measurements of right ventricular enlargement and reflux of contrast to the inferior vena cava have been used among other indexes to gauge right ventricular dysfunction and predict patient mortality [61-65]. Recent technological advancements such as electrocardiogram-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 [66-68].

In general, the data indicate that multidetector CTPA is more sensitive than single-slice CT or other studies, such as V/Q scans. Studies have shown that the high resolution of CTPA makes it possible to detect filling defects in distal subsegmental arteries as small as 2–3 mm in diameter [69]. Only 1% of V/Q scans rated as "high probability" correspond to an isolated subsegmental PE [70], compared with 15% of positive CTPA scans [71]. However, these distal very small clots remain of indeterminate clinical significance and some of them may not require treatment [23].

The general indications for pulmonary catheter 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) 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 c) before placement of an inferior vena cava 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.

Because of the high association of DVT with PE, US evaluation of the venous drainage of the lower extremities may be indicated, especially in patients with signs and symptoms of DVT. US studies include duplex Doppler with leg compression and continuous-wave Doppler [72,73]. The presence of DVT does not indicate the presence of PE but increases 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 [74-76]. For a more detailed discussion on DVT, refer to the ACR Appropriateness Criteria® "Suspected Lower Extremity Deep Vein Thrombosis" [77].

Variant 3: Suspected pulmonary embolism. Pregnant patient.

PE is a leading cause of pregnancy-related mortality in the developed world, accounting for 20% of maternal deaths in the United States [78]. The American Thoracic Society/Society of Thoracic Radiology (ATS/STR) Committee on Pulmonary Embolism in Pregnancy published their Clinical Practice Guideline—Evaluation of Suspected Pulmonary Embolism in Pregnancy, summarized in 7 recommendations that put a high value on avoiding workup with radiation-associated tests if possible [78]. Lower-extremity duplex ultrasonography for assessment of DVT was recommended in pregnant patients with suspected PE and signs and symptoms of lower-extremity DVT as a means of determining the presence of thrombosis suggestive of pulmonary thromboembolism without radiation [78].

The modality of choice (CTPA versus V/Q scan) in pregnant patients remains a matter of debate [79,80]. Fetal radiation doses delivered *in utero* by properly performed diagnostic tests present no measurably increased risk of prenatal death, malformation, or impairment of mental development over the background incidence of these entities. The ATS/STR statement recommends scintigraphy over CTA mainly over maternal, not fetal, radiation dose concerns [78].

When lung scans are indicated in pregnant women, the administered dose of the radiopharmaceutical(s) should be reduced by a factor of 2 or more, with correspondingly longer acquisition times to achieve adequate imaging statistics. Doing so may minimize absorbed radiation 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 <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 PE.

The use of pulmonary MR pulmonary angiography is also of at least theoretical value in pregnant patients, as well as patients in whom the use of iodinated contrast agents is contraindicated [81]. Although 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.

Summary of Recommendations

- Variant 1
  - In patients with low or intermediate clinical probability of PE, normal results on D-dimer testing avoid unnecessary further investigation.
- Variant 2
  - CTPA is highly sensitive and specific.
  - CTPA also has fewer "nondiagnostic" studies than V/Q scans.
  - There is a high association of DVT with PE; therefore, US evaluation of the venous drainage of the lower extremities may be indicated, especially in patients with signs and symptoms of DVT.
- Variant 3
  - Workup with radiation-associated tests should be avoided if possible.

- Lower-extremity duplex ultrasonography for assessment of DVT is recommended in pregnant patients with suspected PE and signs and symptoms of lower-extremity DVT.
- There is still some debate over the preference of CTPA or scintigraphy.

Summary of Evidence

Of the 86 references cited in the *ACR Appropriateness Criteria® Suspected Pulmonary Embolism* document, all of them are categorized as diagnostic references including 11 well-designed studies, 15 good-quality studies, and 27 quality studies that may have design limitations. There are 31 references that may not be useful as primary evidence. There are 2 references that are meta-analysis studies.

The 86 references cited in the *ACR Appropriateness Criteria® Suspected Pulmonary Embolism* document were published from 1979-2015.

While there are references that report on studies with design limitations, 26 well-designed or good-quality studies provide good evidence.

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-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation [82]
- ACR-ACOG-AIUM-SRU Practice Parameter for the Performance of Obstetrical Ultrasound [83]
- ACR Guidance Document on MR Safe Practices [84]
- ACR Manual on Contrast Media [85]

Anticipated Exceptions

If multidetector CTPA is not available, then V/Q scans, pulmonary MRA, and/or lower-extremity US 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 2 modalities nearly equivalent in absorbed dose. If a chest radiograph is abnormal, CTPA has a higher likelihood of being definitive [86].

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

For additional information on the Appropriateness Criteria methodology and other supporting documents go to www.acr.org/ac.

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. Hiorns MP, Mayo JR. Spiral computed tomography for acute pulmonary embolism. *Can Assoc Radiol J.* 2002;53(5):258-268.
18. 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.
19. 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.
20. Schoepf UJ, Costello P. CT angiography for diagnosis of pulmonary embolism: state of the art. *Radiology*. 2004;230(2):329-337.
21. Ritchie G, McGurk S, McCreath C, Graham C, Murchison JT. Prospective evaluation of unsuspected pulmonary embolism on contrast enhanced multidetector CT (MDCT) scanning. *Thorax.* 2007;62(6):536-540.
22. 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.
23. Wiener RS, Schwartz LM, Woloshin S. When a test is too good: how CT pulmonary angiograms find pulmonary emboli that do not need to be found. *BMJ.* 2013;347:f3368.
24. American College of Radiology. ACR–NASCI–SIR–SPR Practice Parameter for the Performance and Interpretation of Body Computed Tomography Angiography (CTA). Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Body_CTA.pdf.
25. 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.
26. 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.
27. Value of the ventilation/perfusion scan in acute pulmonary embolism. Results of the prospective investigation of pulmonary embolism diagnosis (PIOPED). *JAMA.* 1990;263(20):2753-2759.
28. 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.
29. 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.
30. 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.
31. 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.
32. 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.
33. 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.
34. 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.
35. 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.

36. 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.
37. 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.
38. 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.
39. 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.
40. 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.
41. 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.
42. 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.
43. 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.
44. 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.
45. 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.
46. Huisman MV, Klok FA. Magnetic resonance imaging for diagnosis of acute pulmonary embolism: not yet a suitable alternative to CT-PA. *J Thromb Haemost.* 2012;10(5):741-742.
47. Sostman HD, Jablonski KA, Woodard PK, et al. Factors in the technical quality of gadolinium enhanced magnetic resonance angiography for pulmonary embolism in PIOPED III. *Int J Cardiovasc Imaging.* 2012;28(2):303-312.
48. Stein PD, Chenevert TL, Fowler SE, et al. Gadolinium-enhanced magnetic resonance angiography for pulmonary embolism: a multicenter prospective study (PIOPED III). *Ann Intern Med.* 2010;152(7):434-443, W142-433.
49. Schiebler ML, Nagle SK, Francois CJ, et al. Effectiveness of MR angiography for the primary diagnosis of acute pulmonary embolism: clinical outcomes at 3 months and 1 year. *J Magn Reson Imaging.* 2013;38(4):914-925.
50. 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.
51. 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.
52. Venkatesh AK, Kline JA, Courtney DM, et al. Evaluation of pulmonary embolism in the emergency department and consistency with a national quality measure: quantifying the opportunity for improvement. *Arch Intern Med.* 2012;172(13):1028-1032.
53. Lucassen W, Geersing GJ, Erkens PM, et al. Clinical decision rules for excluding pulmonary embolism: a meta-analysis. *Ann Intern Med.* 2011;155(7):448-460.
54. Kelley MA, Carson JL, Palevsky HI, Schwartz JS. Diagnosing pulmonary embolism: new facts and strategies. *Ann Intern Med.* 1991;114(4):300-306.
55. Raja AS, Greenberg JO, Qaseem A, Denberg TD, Fitterman N, Schuur JD. Evaluation of Patients With Suspected Acute Pulmonary Embolism: Best Practice Advice From the Clinical Guidelines Committee of the American College of Physicians. *Ann Intern Med.* 2015;163(9):701-711.
56. Perrier A, Roy PM, Sanchez O, et al. Multidetector-row computed tomography in suspected pulmonary embolism. *N Engl J Med.* 2005;352(17):1760-1768.
57. Warren DJ, Matthews S. Pulmonary embolism: investigation of the clinically assessed intermediate risk subgroup. *Br J Radiol.* 2012;85(1009):37-43.

58. Stein PD, Fowler SE, Goodman LR, et al. Multidetector computed tomography for acute pulmonary embolism. *N Engl J Med.* 2006;354(22):2317-2327.
59. 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 retrolective-prolective cohort study focusing on total diagnostic yield. *Eur Radiol.* 1998;8(1):90-96.
60. 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.
61. Ghuysen 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.
62. 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.
63. 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.
64. 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.
65. 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.
66. 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.
67. 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.
68. 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.
69. Ghaye B. Peripheral pulmonary embolism on multidetector CT pulmonary angiography. *JBR-BTR.* 2007;90(2):100-108.
70. Stein PD, Henry JW. Prevalence of acute pulmonary embolism in central and subsegmental pulmonary arteries and relation to probability interpretation of ventilation/perfusion lung scans. *Chest.* 1997;111(5):1246-1248.
71. Carrier M, Righini M, Wells PS, et al. Subsegmental pulmonary embolism diagnosed by computed tomography: incidence and clinical implications. A systematic review and meta-analysis of the management outcome studies. *J Thromb Haemost.* 2010;8(8):1716-1722.
72. 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.
73. 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.
74. 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.
75. Smith LL, Iber C, Sirr S. Pulmonary embolism: confirmation with venous duplex US as adjunct to lung scanning. *Radiology.* 1994;191(1):143-147.
76. 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.
77. American College of Radiology. ACR Appropriateness Criteria®: Suspected Lower Extremity Deep Vein Thrombosis. Available at: https://acsearch.acr.org/docs/69416/Narrative/.
78. Leung AN, Bull TM, Jaeschke R, et al. American Thoracic Society documents: an official American Thoracic Society/Society of Thoracic Radiology Clinical Practice Guideline--Evaluation of Suspected Pulmonary Embolism in Pregnancy. *Radiology.* 2012;262(2):635-646.
79. 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.
80. 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.
81. 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.

82. American College of Radiology. ACR-SPR Practice Parameter for Imaging Pregnant or Potentially Pregnant Adolescents and Women with Ionizing Radiation. Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Pregnant_Patients.pdf.
83. American College of Radiology. ACR-ACOG-AIUM-SRU Practice Paramater for the Performance of Obstetrical Ultrasound. Available at: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/US_Obstetrical.pdf.
84. Kanal E, Barkovich AJ, Bell C, et al. ACR guidance document on MR safe practices: 2013. *J Magn Reson Imaging*. 2013;37(3):501-530.
85. American College of Radiology. *Manual on Contrast Media*. Available at: http://www.acr.org/Quality-Safety/Resources/Contrast-Manual.
86. 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.