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Imaging of Acute Pulmonary Embolism

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SUMMARY

The past decade has seen a shift in the imaging paradigm for acute pulmonary embolism (PE) from a combination of clinical acumen, ventilation-perfusion scintigraphy, and conventional pulmonary angiography to computed tomographic pulmonary angiography (CTPA). The ability to perform CT rapidly with direct visualization of thrombi allows for rapid and reliable diagnosis or exclusion of PE in the vast majority of cases. In the same setting, CT can provide information on right heart function, offer an evaluation of the deep venous system through indirect CT venography, as well as allow for the detection of alternative diagnoses that may account for the patient's symptoms. Published experience with CTPA has established that a negative result reliably excludes clinically significant PE in more than 98% of cases. As a result, CT has become the preferred first-line imaging test in the evaluation of suspected acute PE.

Key Words: Computed tomography; pulmonary angiography; ventilation-perfusion scintigraphy.

INTRODUCTION

Acute pulmonary embolism (PE) is a relatively common event with a wide spectrum of clinical presentations that range from small asymptomatic and incidentally detected

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subsegmental PE to life-threatening central PE causing hypotension, myocardial infarction, and cardiogenic shock. The overall incidence has been estimated at approx 1 per 1000 population in the United States (1), and 3-mo mortality may be higher than 15% (2). Thus, because of the relatively high mortality of PE and the treatable nature of the disease, the diagnosis is often sought in the evaluation of acute dyspnea and hypoxia. Imaging studies remain a critical step for establishing the diagnosis.

CHEST X-RAY

The chest radiograph is rarely, if ever, diagnostic of PE, and thus the main role of chest radiography is to identify important alternative diagnoses such as congestive heart failure and pneumonia. In the latter case, the diagnosis of PE can be dismissed early and the need for further, advanced imaging studies may be obviated. On the other hand, chest radiographs may aid in triaging patients suspected of having PE to the next imaging test. For instance, if the chest radiograph is normal, there is a high likelihood of a diagnostic result from ventilation-perfusion (V/Q) scintigraphy. If, however, the chest radiographs are abnormal, V/Q scanning is likely to be nondiagnostic and cross-sectional imaging, particularly computed tomographic pulmonary angiography (CTPA), would be the preferred strategy. This is of particular value when weighing the risks and benefits of performing these tests, particularly in consideration of radiation dose and intravenous contrast.

In the setting of acute PE, chest radiographs are often normal or show minor abnormalities such as subsegmental atelectasis and small pleural effusion (3). The presence of segmental or lobar atelectasis as well as large pleural effusion should suggest a diagnosis other than PE, although, unfortunately, the two coexist on occasion. Pulmonary infarcts are uncommonly visualized on chest radiographs (Fig. 1), but, when present, are seen as wedge shaped air-space opacities typically located at the costophrenic sulci (also known as Hampton's hump). With extensive PEs and large central clots, regional hypoperfusion may be evident as areas of decreased lung attenuation with an associated paucity of vascular markings (Westermark's sign).

IMAGING THE DEEP VENOUS SYSTEM

This diagnostic test is discussed in more detail in the following chapter (Chapter 3). Because duplex venous ultrasound is a relatively easy study to perform and interpret, some authors have advocated bilateral lower extremity studies early in the algorithm for the work-up of PE. The rationale is that deep venous thrombosis (DVT) and PE are treated in essentially the same manner and that a positive result would thus obviate the need for further imaging. As explained in Chapter 7, this may indeed be a reasonable consideration in many patients suspected of having PE. It should be noted, however, as a limitation of this strategy, that failure to diagnose PE in the setting of venous thromboembolism may result in incorrect (over)diagnosis of PE recurrence during follow-up, particularly with the use of V/Q scintigraphy (4,5).

V/Q SCINTIGRAPHY

Validation

Prior to widespread usage of CT, V/Q scintigraphy was the test of choice to screen for PE. The most recent source of knowledge comes from the Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED), a large multi-institutional study to deter-

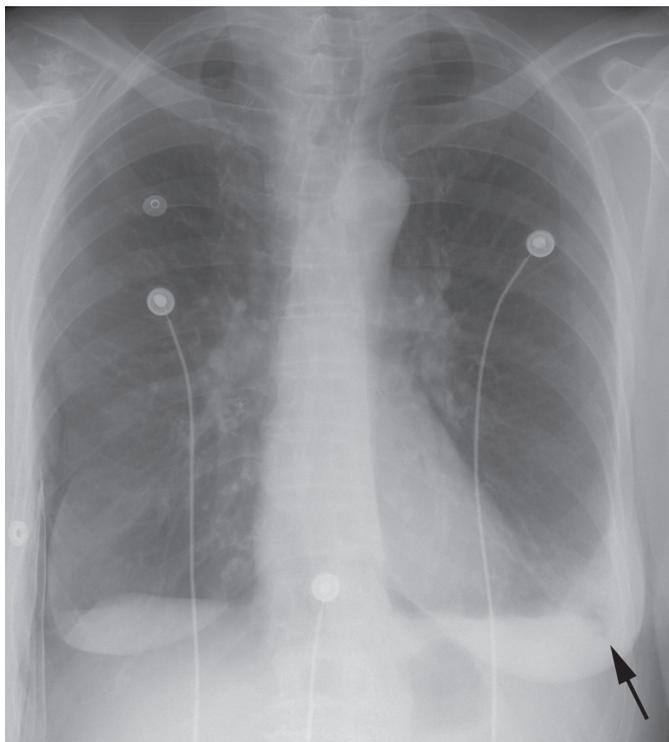


Fig. 1. Pulmonary infarct. Frontal chest radiograph reveals wedge-shaped area of air-space disease in left costophrenic sulcus (arrow), also known as Hampton's Hump.

mine the utility of V/Q scintigraphy with conventional angiography as the reference standard (6). Rather than the traditional interpretation of the test as “positive” or “negative,” the results of the study were used to stratify the chance of PE based on the scintigraphic pattern (Table 1). As the intent of the study was to promote V/Q scintigraphy as a screening test, the results were presented to maximize sensitivity. In order to accomplish this task, however, all but the normal scans had to be grouped together as an abnormal result, raising the sensitivity to 98% (6). Unfortunately, this also resulted in a very low specificity of 10% (6). Based on the results of this study as well as the prior work by Hull (7,8), venous ultrasound followed by conventional angiography and/or venography (if the ultrasound was negative) was recommended to follow all but normal lung scans (9).

Using clinical suspicion as a guide (*see* Chapter 1), the accuracy of V/Q scintigraphy can be improved. For instance, combining a clinical probability of less than 20% with a low-probability scan indicated a mere 4% likelihood of PE (6). Further refinements of the data were also used to modify low-probability studies (10) and then create a “very low-probability” category with the risk of PE being less than 10% (11,12). It should be noted, however, that current evidence supports withholding anticoagulation only in the setting of a normal V/Q scan *and* negative DVT evaluation (6,13).

Despite the available data and recommendations, it is clear that the results of V/Q scintigraphy are frequently misapplied (14–16). Interpreting physicians may use their own “gestalt” approach rather than following the established criteria (17). Patients with low or intermediate probability studies often do not undergo further testing despite the published recommendations (15,16), perhaps owing to a lack of understanding of V/Q scintigraphy's

Table 1
Modified PIOPED Criteria for Pulmonary Embolism (PE) (10)

Category	% Posttest probability of PE
Normal	<2
– No perfusion abnormalities	
Very low probability (11)	<10
– Nonsegmental perfusion defect	
– Perfusion defect smaller than chest X-ray finding	
– Stripe sign	
– Triple match mid/upper lung	
– Less than three small segmental defects	
Low probability	<15
– Multiple matched defects	
– Defect with larger chest X-ray abnormality	
– Less than three small segmental defects	
– Nonsegmental defects	
Intermediate probability	~33
– One moderate or less than two large defects	
– Corresponding lower lung zone defect and chest X-ray abnormality	
– Ventilation-perfusion defects and small effusion	
– Difficult to categorize as high or low probability	
High probability	>85
– Two large segmental perfusion defects without ventilation or chest X-ray abnormality	
– One large and two moderate perfusion defects	
– Four moderate perfusion defects	

role as a screening rather than a diagnostic test. Based on the rapid advances of CT technology and the limitations of V/Q scintigraphy, utilization of this test is decreasing (18).

Interpretation

Besides the published PIOPED criteria (*see* Table 1), other criteria proposed earlier by McNiel (19), Biello (20), and Hull (8) can be used to assess the probability of PE. Although these sets of criteria have (subtle) differences, none is clearly superior to the rest (21). Moreover, despite the wealth of information, interpretation remains a subjective process in clinical practice and, at the end of the analysis, the category (probability of PE) may be assigned on a “gut feeling” rather than objective use of fixed criteria. This leads to intraobserver variations that may not disappear even with fixed training (22,23). It appears that the Hull criteria have the least intraobserver variability when compared with the PIOPED criteria or the gestalt approach (17). Despite conventional wisdom, it does not appear that the presence of underlying disease or critical illness affects the overall reliability of V/Q scintigraphy (24,25).

The rationale of V/Q scintigraphy lies in the fact that portions of lung subtended by a vessel will remain ventilated when perfusion is interrupted by an embolus, resulting in V/Q mismatch. This appears as a wedge-shaped defect in the perfusion scan with normal ventilation. The probability is then based on the size and number of mismatched segments and subsegments (Fig. 2). In the presence of underlying lung disease or disordered ventilation, interpretation can be more difficult. A matched segment may occur as a result

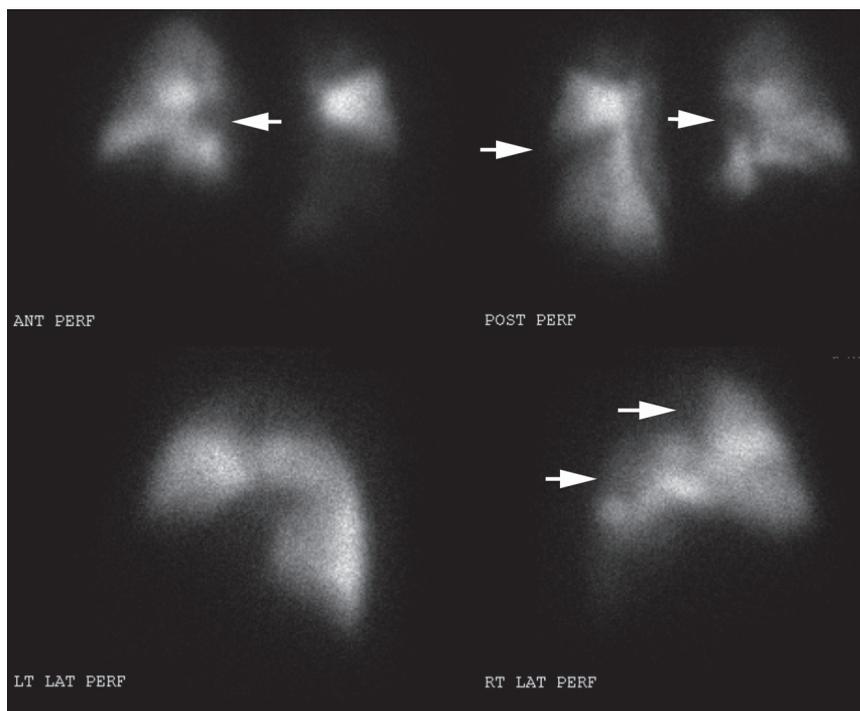


Fig. 2. Acute pulmonary embolism. Perfusion scan reveals multiple wedge-shaped perfusion defects (arrows). High-probability scan in setting of normal ventilation.

of shunting of blood flow away from nonventilated segments, embolic disease to poorly ventilated lung tissue, or pulmonary infarction. When a triple match (abnormal chest radiograph, ventilation, and perfusion in the same region) occurs in the upper lobe, it is generally considered to be due to shunting of blood, whereas a triple match occurring in the lower lobe may be due to pulmonary infarction.

CONVENTIONAL PULMONARY ANGIOGRAPHY

Validation

The technique of conventional angiography dates back to the 1950s. It gained increasing popularity over the next two decades and was validated by negative outcome studies. Still, the early data were somewhat limited and did not necessarily reflect today's imaging patterns. In the largest original cohort of 247 patients (imaged over a 6-yr period), the rate of definitive diagnosis, positive or negative, was 74% and subsequent development of PE was not reported (26). In the PIOPED study, the rate of subsequent PE after 1 yr of follow-up was 1.6% for 380 negative angiograms (27). When the results of the PIOPED trial and the three other outcome trials performed at that time are analyzed together, 15/733 (2.0%) subjects had subsequent PE after a negative pulmonary angiogram (7,27–29). Primarily based on these studies and the lack of other imaging options, catheter pulmonary angiography was regarded as gold standard for imaging PE.

Although relatively invasive compared to other imaging modalities (30,31), catheter angiography is a rather safe procedure. Major complications including hematoma, renal failure, respiratory distress, and death occur in less than 1% of the patients, and the death

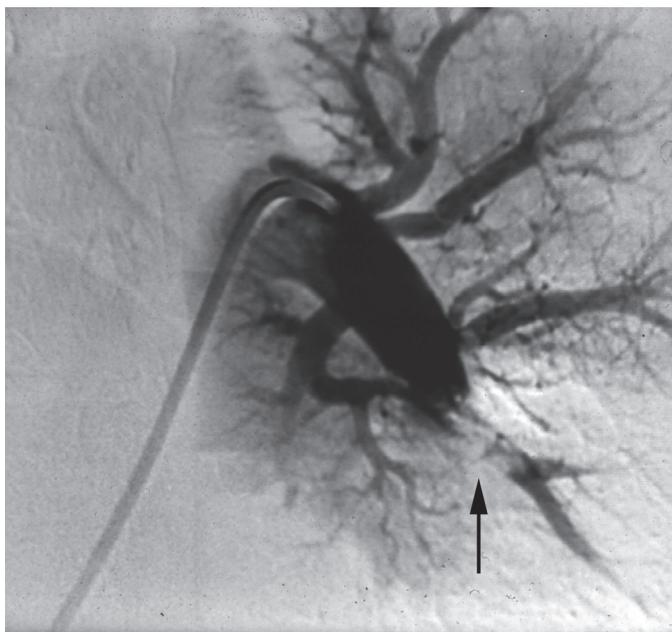


Fig. 3. Acute pulmonary embolism. Selective digital subtraction angiography in left pulmonary artery reveals segmental branch filling defect (arrow) diagnostic of pulmonary embolism.

rate across several studies was less than 0.5% (30). Despite the safety record, many physicians are reluctant to order this study, particularly in patients in whom thrombolytic treatment is either planned or already being administered.

Although negative outcome studies establish the safety of withholding anticoagulation in a negative study, they cannot *per se* establish accuracy. Attempts to determine the reproducibility of conventional angiogram interpretations amongst different observers has met with mixed success. In the PIOPED study, observer agreement overall was 81% (98% for lobar, 90% for segmental, and 66% for subsegmental embolus), and the agreement on negative results became significantly less as the quality of the study decreased (30). Clearly, interobserver variability at the subsegmental level is a significant problem ranging from 40–66% for two observers (30,32–34). Given that the use of catheter angiography is in decline (35,36), the overall reliability in the hands of relatively inexperienced angiographers may be significant and should be considered a major limitation at this time.

Interpretation

Four basic patterns of abnormality have been described: (1) intraluminal filling defects; (2) vascular cut-offs; (3) regional oligemia; and (4) asymmetric flow (26,37). The first two are considered to be the most specific findings of PE. Intraluminal filling defects usually result from incomplete occlusion of a vessel and can sometimes be difficult to detect because of flow around the thrombus. Vascular cut-offs result from complete occlusion and are also difficult to detect in peripheral vessels (Fig. 3). Generally, the lack of perfusion distal to a vascular cut-off is considered secondary evidence of thrombus. Other pathophysiologic factors may lead to regional oligemia and flow asymmetry, and thus detection of such abnormalities requires a careful search for definitive signs of emboli. By themselves, oligemia and flow asymmetry are rather nonspecific findings.

MAGNETIC RESONANCE IMAGING

MRI may become a valid tool to evaluate patients with suspected PE and absolute or relative contraindications to computed tomography (CT) such as renal failure or pregnancy. Unfortunately, there are few well designed clinical trials of MRI. A recent meta-analysis found that only 3 of 28 studies performed met stringent criteria for the evaluation of a diagnostic imaging technique (38). This study also revealed that gadolinium-based MRI has good diagnostic sensitivity (77–87%) and specificity (95–98%) (39–41). The major disadvantages are long examination times, the need for a relatively long breath hold (a crucial problem in patients with acute PE), and the inappropriateness of the method for imaging critically ill patients. However, as technology advances and breath-hold techniques are refined, MRI is likely to emerge as a viable alternative for patients with contraindications to contrast-enhanced CT. An example of this is magnetic resonance angiography using gradient-recalled echo techniques with sensitivity encoding. In a preliminary study (42), the breath hold for this technique was approx 36 s with a per-patient sensitivity and specificity of 92 and 94%, respectively, when compared to conventional angiography. Although sensitivity dropped to 70% in peripheral lung zones, the results overall compared favorably to multidetector CT.

COMPUTED TOMOGRAPHY

With rapid improvements in technology, the current generation of multidetector CT scanners allows an acquisition of the entire thorax with submillimeter resolution within a comfortable breath hold of less than 10 s (43). Improvements in temporal resolution with rotation times of 0.5 s and less reduce the number of nondiagnostic CT scans, particularly in patients with underlying lung disease (44). Although 1.0- to 1.25-mm slice thickness may not be necessary to detect large PE, it clearly provides a better depiction of subsegmental vessels and improves interobserver agreement (45,46).

To obtain a diagnostic study, a rapid contrast bolus (3–5 ccs per second) and accurate bolus tracking are critical. A secure intravenous catheter is necessary, preferably 18–20 gauge in the antecubital fossa. A saline chaser helps to reduce artifacts from dense contrast in the superior vena cava, but is not universally available at this time.

Validation

CT has become the method of choice for imaging PE in clinical routine in most institutions. Although meta-analyses have suggested that CT has not been adequately evaluated compared to the “gold” standard (47–49), these reports focused on only earlier studies. The most recent comparison of four-row multidetector CT (MDCT) and digital subtraction angiography showed 100% sensitivity and 89% specificity for CT with three “false-positives”, which were, however, considered as true-positive CT and false-negative conventional angiography at review (50). Direct comparison of CT to conventional angiography may not be appropriate for other reasons as well. The interobserver reproducibility for a confident diagnosis of PE with MDCT exceeds the correlation with selective pulmonary angiography (34,46,51). Because of the reluctance to perform routine conventional angiography, and perhaps as important, a declining experience in the interpretation of conventional pulmonary angiograms, the validity of conventional angiography as a diagnostic standard is no longer certain. PIOPED II, a large multicenter study to assess the accuracy of CT, used a composite diagnostic standard rather than performing

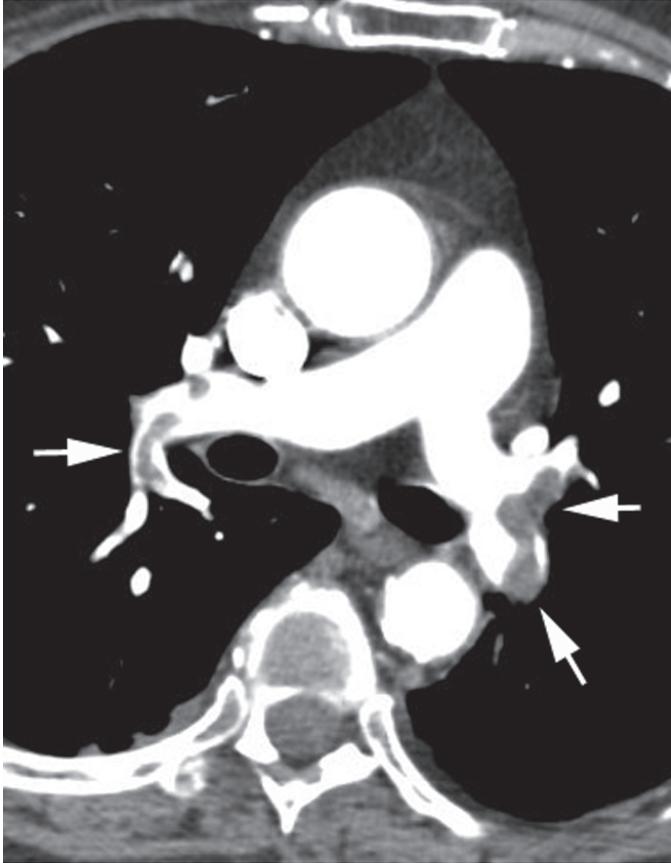


Fig. 4. Acute pulmonary embolism. Contrast-enhanced axial computed tomography reveals low-attenuation emboli in the right and left pulmonary arteries (arrows).

conventional angiography in all cases (52). The preferable means for validation of CT is therefore the performance of negative outcome studies, the same scientific investigations used to establish conventional angiography as the reference standard.

Negative predictive value of CT has consistently been shown to surpass 96% both with single detector (53–59) and multidetector techniques (60–68). Underlying lung disease (59), inpatient status (54), and results of V/Q scan (56,58) did not appear to have appreciable effects on the negative predictive value. Thus, if the CT study is interpreted as negative for PE with acceptable image quality, anticoagulation can possibly be safely withheld without adversely affecting patient outcome (*see also* Chapter 7). It should be noted in this regard that CT has undergone much more rigorous evaluation in far greater numbers of patients than conventional angiography to be established as the “gold” standard in the diagnosis of PE (69).

Interpretation

The diagnosis of PE is usually straightforward, relying on the direct observation of a central filling defect surrounded by a rim of contrast in a pulmonary artery (Figs. 4 and 5). Often emboli lodge at bifurcation points and continue into both branch vessels. A sharp vessel cut-off or absence of vessel filling also provides evidence of PE, but may be more

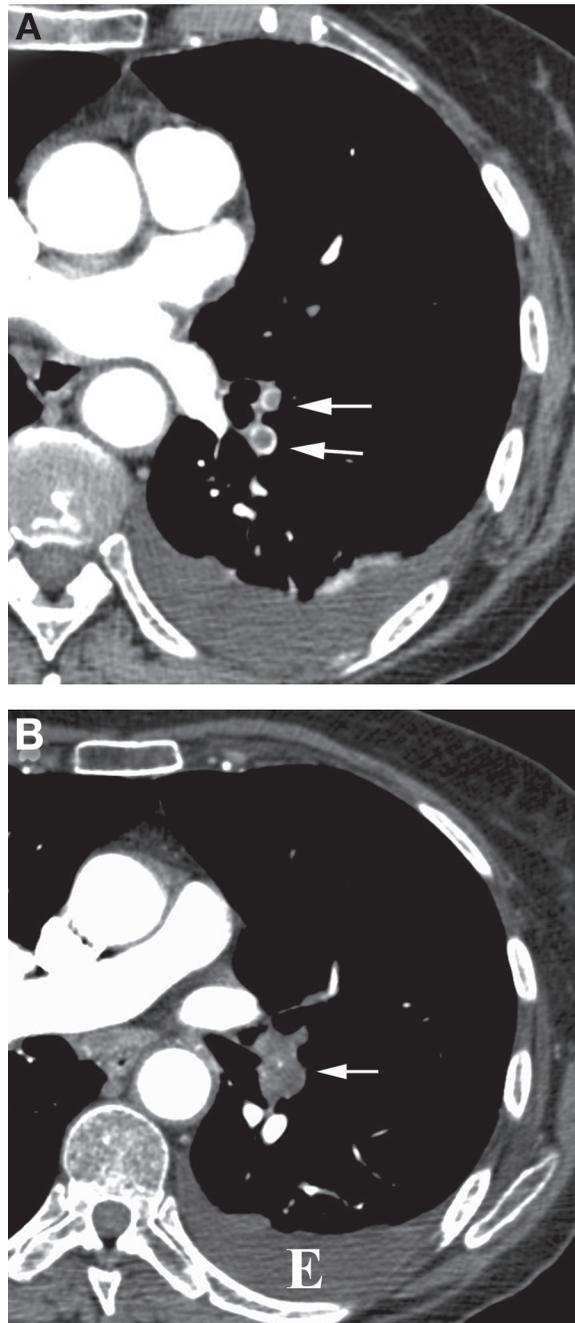


Fig. 5. Appearances of acute pulmonary embolism on computed tomography. **(A)** Filling defect surrounded by rim of contrast (arrows). **(B)** Complete vascular cut-off (arrow) with absent distal flow. Note also left pleural effusion (**E**).

difficult to perceive. Vessels that run parallel to the axial plane, particularly right middle lobe and lingual branches, are often better evaluated with coronal, sagittal, or off-axis oblique reformations, which can be performed rapidly at a number of advanced viewing work stations (Figs. 6–8). Reformations allow these vessels to be viewed in cross-section

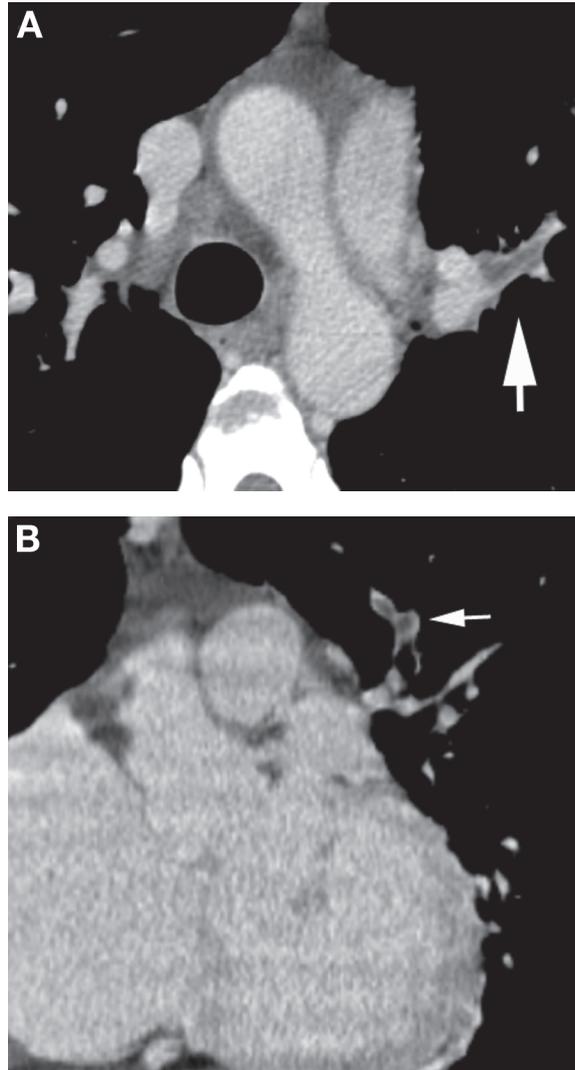


Fig. 6. Value of reformatted images. (A) Axial image reveals apparent filling defect in anterior segmental branch of left upper lobe (arrow). Appearance can be mistaken for volume averaging with adjacent structures. (B) Oblique coronal reformatted image reveals typical appearance of filling defect surrounded by rim of contrast (arrow).

similar to upper and lower lobe vessels and increase diagnostic confidence, as well as reduce false-positive studies due to artifacts (70).

Secondary findings may also be present to suggest the diagnosis. Infarcts present as peripheral wedge-shaped areas of ground-glass opacity or consolidation (Fig. 9), and in one study occurred in 25% of cases with PE (71). Localized oligemia (Fig. 10) may also be seen (CT Westermarks's sign), although in most cases the embolus causing hypoperfusion is easily identifiable. Nonspecific abnormalities such as subsegmental atelectasis and small pleural effusions are often encountered both in patients with and without PE. Often, these findings are helpful in alerting the study interpreter to carefully evaluate the relevant vascular supply. A clear benefit of CT is the depiction of alternative diagnoses not otherwise suspected when PE is absent (71,72).

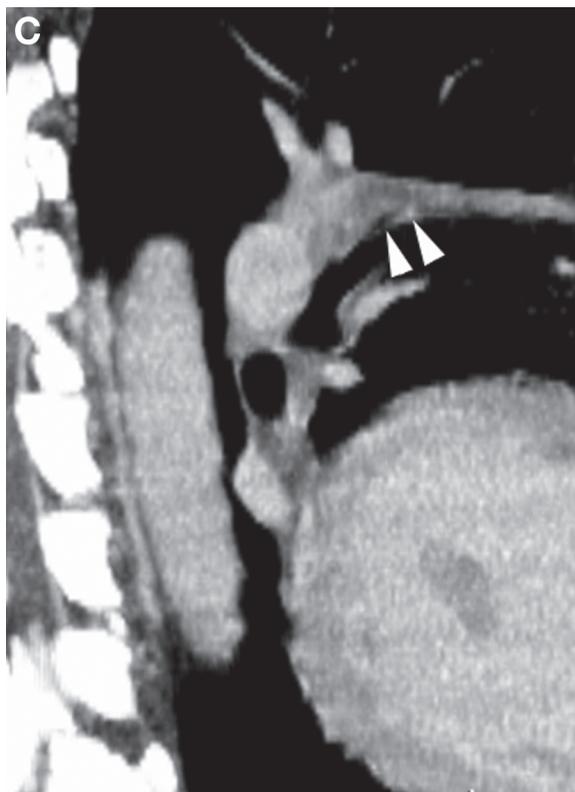


Fig. 6. (C) Oblique sagittal reformatted image defines extent of embolus within the vessel (arrowheads).

Pitfalls and Artifacts

Difficulties in interpreting CT images may be the result of problems with contrast enhancement, image reconstruction, and patient cooperation. Although usually not a problem in clinical practice, dense opacification of the superior vena cava can occasionally cause beam-hardening artifacts to obscure the pulmonary arteries in the medial right upper lobe. On the other hand, a poor bolus is a limitation often difficult to overcome, as contrast differences between an embolus and vessel lumen are difficult to detect. Occasionally, narrowing the window and level setting will allow for more confident interpretation, but in most cases either a repeat bolus of contrast or an alternative imaging technique should be performed.

Stair-step artifacts can mimic PE by simulating filling defects on axial images. They can usually be identified by alternating images of increased and decreased vascular attenuation and confirmed by bands of low and high attenuation on multiplanar reformations (Fig. 11).

Despite scan times approaching 5–10 s, dyspneic patients still may not be able to adequately suspend respiration. The motion from respiration can blur vessels making it impossible to detect emboli. Respiratory motion is best confirmed by viewing at lung window settings. Motion artifacts due to transmitted cardiac pulsation particularly affect the right middle lobe and the lingual and medial lower lobes. Electrocardiogram-gating of chest CT scans reduces artifacts caused by cardiac pulsation and improves the evaluation of adherent thoracic structures (73,74); however, this technique also lengthens the breath

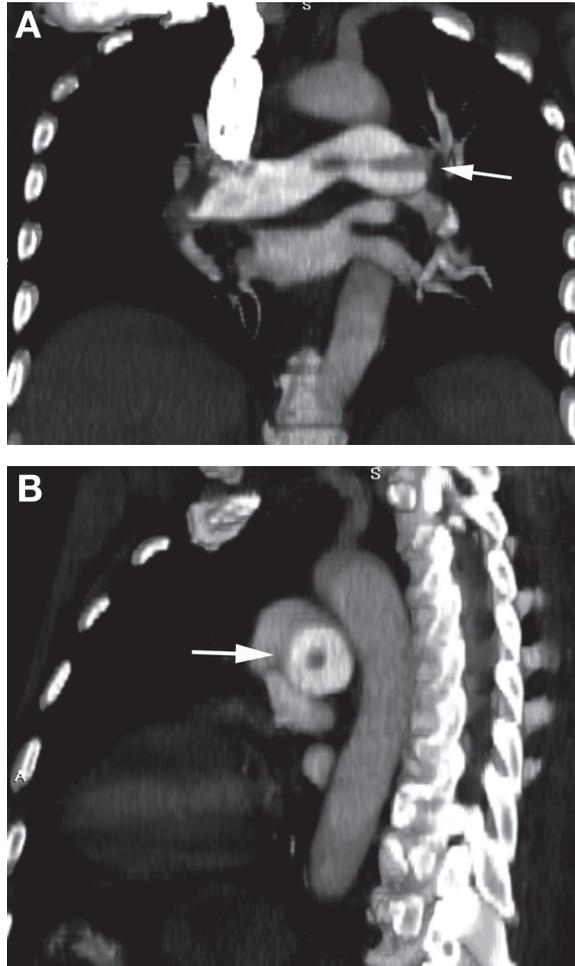


Fig. 7. Using three-dimensional images to define the extent of disease. **(A)** Coronal thick-slab volume rendered image reveals saddle embolus extending into both right and left pulmonary arteries (arrow). **(B)** Sagittal thick-slab volume rendered image allows for better analysis of the degree of occlusion by saddle embolus (arrow).

hold (potentially substituting breathing artifact for pulsation artifact) and increases the radiation dose.

Subsegmental Emboli

Subsegmental emboli are a vexing imaging and clinical problem (Fig. 12). One of the leading criticisms of CT is the inconsistent depiction of subsegmental vessels in earlier studies. This is a flawed argument, as V/Q scans would most likely be interpreted as low- or very low-probability in the setting of isolated subsegmental emboli. Such findings generally do not lead to further testing (75,76), and the interobserver variability of conventional angiography is also poor at the subsegmental level (30,34). Thus, there is no good standard for assessment of subsegmental emboli. Perhaps the greatest advantage of multidetector CT is the improved and more consistent visualization of subsegmental pulmonary arteries up to sixth and seventh order branches (77). At 1-mm collimation, optimal analysis of subsegmental vessels is possible and there is a higher detection rate of small

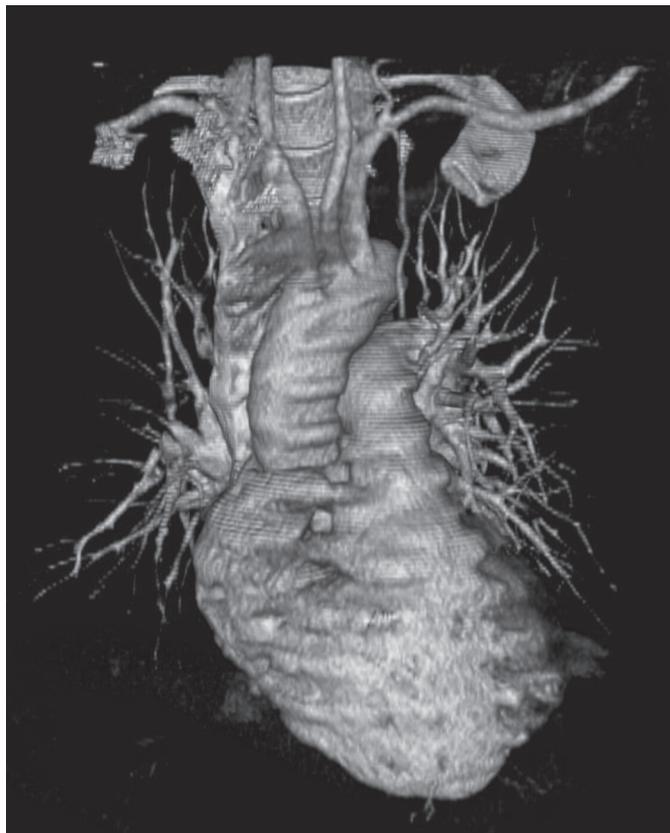


Fig. 8. Using three-dimensional images to define the extent of disease. Frontal projection of three-dimensional volume rendering reveals markedly diminished flow to right lung evidenced by asymmetry of pulmonary vessels.

emboli than with thicker collimation (46,78). However, although there may be no doubt among the interpreting radiologists as to the absence or presence of small isolated emboli based on a good-quality MDCT scan, such findings may be difficult to “prove” in correlation studies.

It has also been suggested that CT may be too sensitive. In one study, 37% of subjects with a CT diagnosis of isolated subsegmental PE did not receive anticoagulation and had no adverse outcome (79). It may be that, in the absence of DVT as indicated by compression ultrasound or indirect CT venography, patients with adequate cardiopulmonary reserve who are otherwise at low risk may not need treatment (80). Unfortunately, there is no good evidence to suggest when it is safe or advantageous to withhold anticoagulation.

CT Assessment of Severity and Right Ventricular Dysfunction

Right heart failure remains a major cause of mortality in patients with acute PE (81). Because of increased pulmonary vascular resistance and hypoxic vasoconstriction, the pressure in the right ventricle rises and, in massive PE, may result in dilation and hypokinesis of the right ventricular myocardium. Traditionally, echocardiography has been utilized to make this determination (82) (*see* Chapter 4). However, information about right ventricular dysfunction can also be gleaned from CT. In response to major PE, there is relative

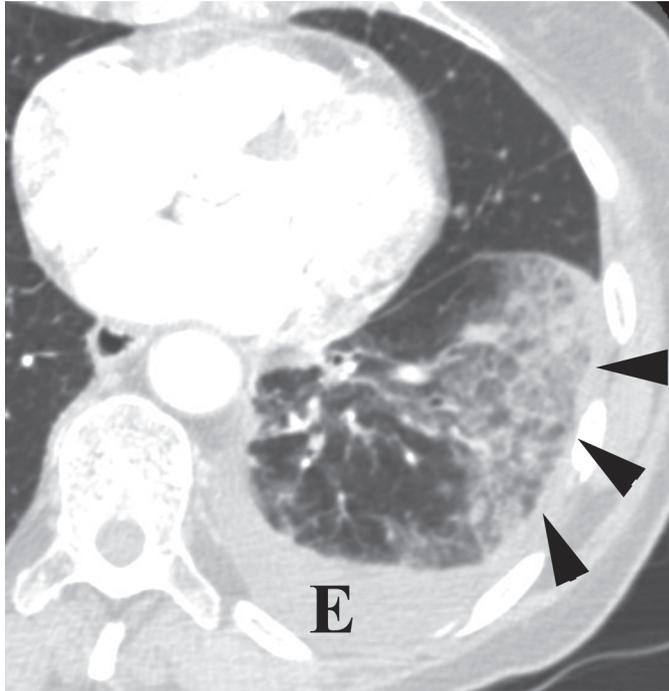


Fig. 9. Pulmonary infarct on computed tomography. Axial image reveals wedge-shaped area of mixed ground glass opacity and consolidation (arrowheads) with associated pleural effusion (E).

enlargement of the right ventricle compared to the left ventricle, although evidence suggests that this may be more a function of left ventricular collapse than right ventricular dilation (83). Nonetheless, the right ventricular/left ventricular ratio (RV_D/LV_D) correlates relatively well with clinical severity, and a ratio greater than 1.5 appears to be sufficiently diagnostic of “massive” PE (84,85). Indeed, in patients with a (RV_D/LV_D) greater than 0.9, significantly more adverse events were observed. Increases in RV_D/LV_D and bowing of the intraventricular septum (Fig. 13) to the left have been associated with the need for admission to an intensive care unit. The major limitation of CT in severity assessment, particularly compared to echocardiography, is the inability to obtain dynamic information including wall motion abnormalities and tricuspid valve regurgitation (86).

A second means of assessing severity can be derived from the degree of vascular obstruction noted at CT. Scoring systems based on conventional angiography such as the Miller index (87) have been adapted for use in CT. The most commonly used system assigns a value of 0, 1, or 2 to each segmental artery indicating no obstruction, partial obstruction, or complete occlusion (88). More proximal emboli are scored based on the total of segmental vessels in the affected vascular territory. This results in a maximum score of 40 and the degree of obstruction is presented as a percentage. An obstruction index of 40% or greater has been correlated with right ventricular dilation at echocardiography (88) and, in one small study, five of six subjects who died of PE had an obstruction index of greater than 60% (89). Still, as evidenced by retrospective studies, there is clearly overlap between “severe” and “nonsevere” PE when relying on the obstruction index (83). From a variety of studies, it appears that at an obstruction index threshold greater than 40% correlates with severity and need for aggressive therapy, but does not act as an independent

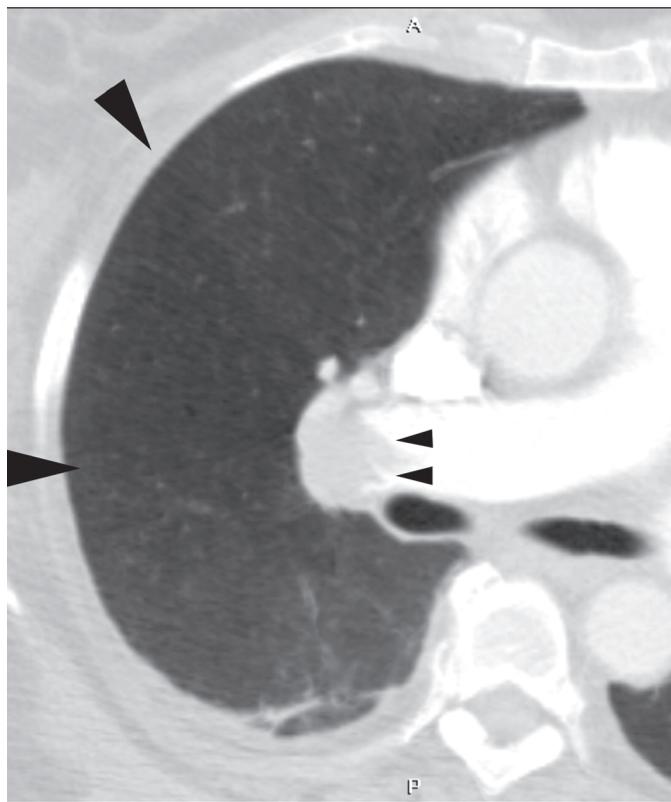


Fig. 10. Computed tomography Westermark sign. Thin-slab axial minimum intensity projection image reveals wedge-shaped region of hypoperfusion (large arrowheads) relative to normal parenchyma due to central pulmonary embolism (small arrowheads).

predictor of mortality (83,86,90). In clinical practice, using this form of severity assessment is more cumbersome than RV_D/LV_D ratio.

RADIATION DOSE CONSIDERATIONS

The effective dose for the typical CT for PE ranges from 3–6 mSv and the absorbed dose in breast tissue is approx 21 mGy, depending on the tube current (91). By way of comparison, screening mammography has an approximate breast dose of 2.5 mGy (91). In the vast majority of cases, the risk-benefit ratio for imaging clearly favors performing the examination, two clinical scenarios warranting particular attention. In young women with normal chest radiographs, there is a high likelihood of a diagnostic V/Q scan and a lower breast-absorbed dose. In pregnant patients (*see* Chapter 17), because of the excretion of radiopharmaceutical via the urinary bladder, the absorbed radiation dose to the developing embryo is higher, 1–2 mGy, for V/Q scan vs 0.1–0.2 mGy for chest CT, and thus CT is favored (92,93), although the radiation dosage in both imaging procedures is well below the fetal threshold of 50 mSv.

With V/Q scanning, radiation dose can be lowered in two ways. Under certain circumstances it is possible to perform the exam without ventilation images, e.g., in an otherwise healthy young patient with normal chest radiograph. Similarly, the radio-labeled macro-aggregated albumin particles can be reduced to half for perfusion imaging. For CT, new

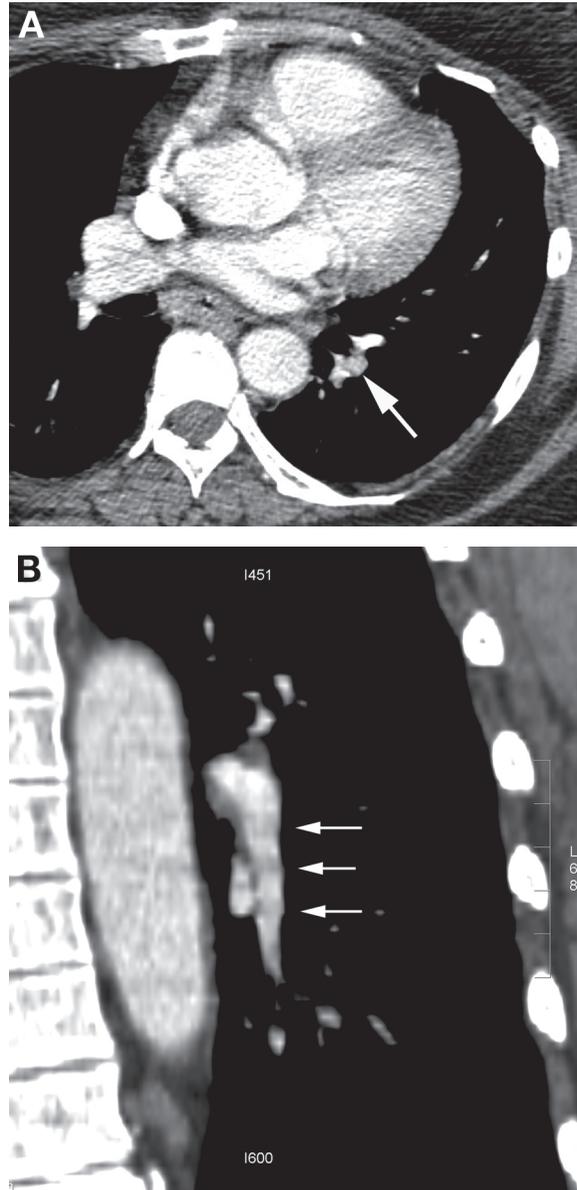


Fig. 11. Stair-step artifact. **(A)** Axial image shows relative decrease in attenuation in basilar segmental vessel (arrow), an appearance that may be mistaken for pulmonary embolism. **(B)** Coronal reformat image reveals typical stair step appearance at multiple levels (arrows). Embolus would appear as extending along the long axis of the vessel.

techniques such as tube current modulation (available on all new multidetector scanners) as well as manually lowering tube current mA and tube rotation time will decrease radiation dose (94). If these parameters are lowered too much, however, the result can be excessive quantum mottle and a nondiagnostic CT exam. Thus, CT exams require a careful balancing of dose and image quality. The specific effect of low-dose techniques on the detection of PE has not been scientifically evaluated to date.

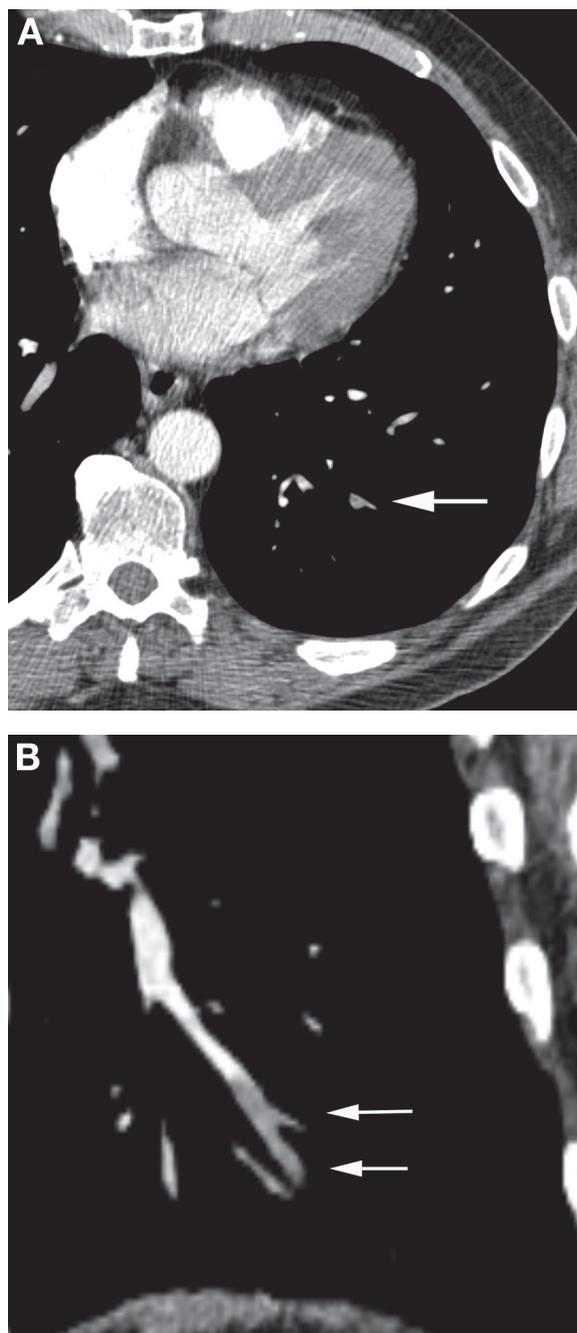


Fig. 12. Subsegmental embolus. (A) Axial image reveals tiny filling defect in small basilar pulmonary artery (arrow). (B) Oblique coronal reformatted image along vessels long axis confirms presence and documents extent of embolus (arrows).

COST-EFFECTIVE IMAGING

Because of the wide array of studies available for the diagnosis of PE, cost-efficacy analysis becomes a complex undertaking and depends on the sensitivity assigned to CT compared to the other competing strategies, and the pretest clinical probability. Several

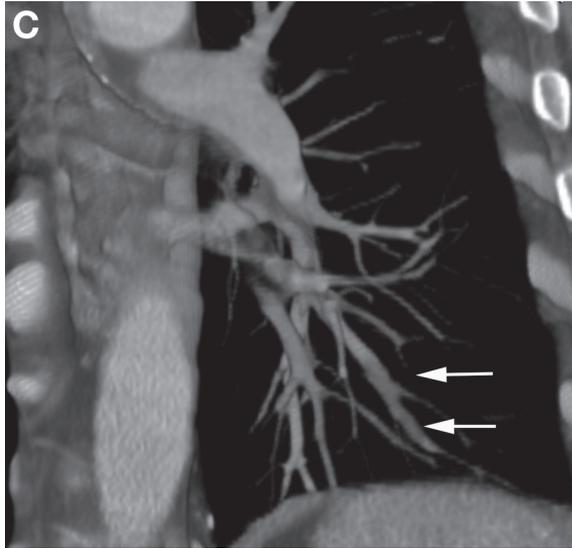


Fig. 12. (C) Coronal thick slab volume rendered image shows embolus (arrows) in relationship to adjacent normal arteries. The defect that would be produced at ventilation-perfusion scan would be expected to be read as very low probability for pulmonary embolism.

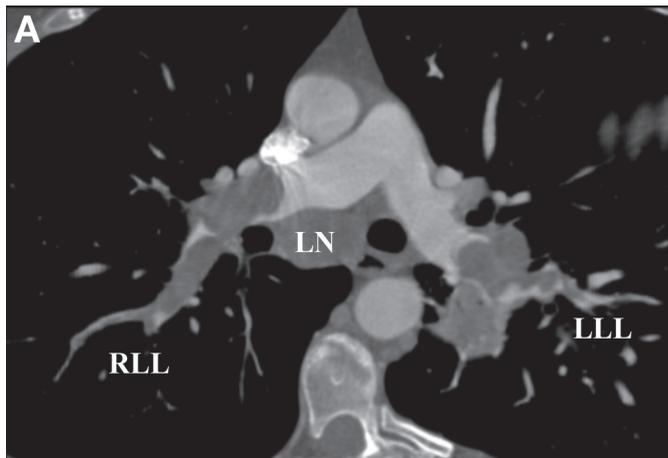


Fig. 13. (A) Curved reformatted image created to display main and lower lobe arteries reveals extensive emboli with extensive vascular occlusion. LN, subcarinal lymph node related to known primary lung malignancy.

analyses have been performed, based primarily on data from single-detector CT (95–97). Assuming an 85% diagnostic sensitivity, CT strategies become more cost-effective than V/Q strategies (95,96), although it should be emphasized that these strategies also require the use of ultrasound and D-dimer testing (*see* Chapter 7). Unfortunately, these analyses omit an important factor for the use of CT, i.e., the ability to rapidly indicate alternative diagnoses that would also favor CT over any one of the competing strategies (98). When the clinical probability of DVT is high, strategies that include lower extremity ultrasound followed by CT appear to be the most efficacious use of imaging, with a cost-effectiveness ratio below \$20,000 (US dollars) per life saved (99). Whether indirect CT venog-

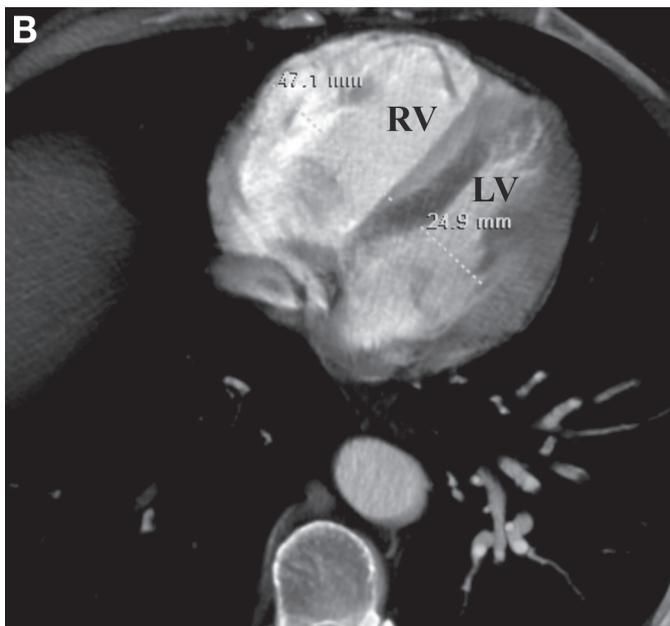


Fig. 13. (B) Axial image through heart reveals bowing of the interventricular septum to left and $RV_D/LV_D = 1.9$, both signs of right ventricular strain.

raphy in the setting of CT for PE will result in lower costs through the elimination of ultrasound studies is not clear.

CONCLUSION

Although many options remain for the diagnosis of PE, the preferred strategy is to use CT as a first-line diagnostic test in the vast majority of circumstances.

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