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Imaging of acute pulmonary emboli

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Pulmonary embolism (PE) is a significant cause of surgical morbidity and mortality after surgical procedures. Venous stasis caused by immobilization, endothelial damage, and malignancy is a physiologic factor that predisposes to thromboembolism [1] and is common in the surgical patient. Because clinical signs and symptoms such as chest pain, dyspnea, and tachycardia are notoriously nonspecific, radiologic imaging is the mainstay of diagnosis. In this article the authors discuss the various methods of imaging PEs in surgical patients.

The incidence of PE in surgical patients is high and occurs throughout the spectrum of surgical patients. In one large series of trauma patients, the development of PE was found to confer an overall tenfold increase in mortality, to 26% [2]. Perhaps the best numerical description of the importance of PE to surgeons is found in the extensive pathology series of Lindblad, who found that 31.7% of all surgical patient autopsies from 1981 to 1988 had PE. Twenty-nine percent of these autopsy-proven emboli were considered to be fatal [3]. Other studies of surgical mortality in inpatients show similar results [4]. Modern laparoscopic procedures also carry a risk of fatal PE [5]. Pulmonary embolization has even been reported during such minimally invasive procedures as percutaneous discoplasty [6–8]. It is therefore important to maintain a high index of suspicion in all surgical patients.

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The physiology of PE forms the basis for its detection and has been reviewed extensively [1]. PEs usually begin as thrombosis of the calf veins. They typically propagate to the deep venous system of the leg and thigh (popliteal vein, superficial femoral veins, or common femoral veins), although in recent years an increasing number of catheter-related venous thromboses have been seen that originated at sites of central venous catheter placements. When in the deep venous system, thrombi can dislodge or fragment and travel to the lungs. DVTs are usually asymptomatic [9] and are therefore usually not suspected before PE [10]. DVT or PE can be imaged at any of these stages: as DVT in the legs by way of ultrasonography or venography, directly in the pulmonary arterial tree by way of conventional angiography (CA), CT pulmonary angiography (CTPA), or MR angiography (MRPA), or by way of its end-effects on pulmonary perfusion and ventilation (V/Q scanning) or the lung parenchyma by way of chest radiograph (CXR). Large central emboli can even be identified by transesophageal echocardiography (TEE). The availability of so many different tests, each with its own strengths and weaknesses, can be somewhat perplexing. In this article the authors attempt to provide a framework for the diagnosis of PE.

Chest radiograph

A plain CXR is an essential part of early diagnostic investigation because it has a valuable role in the exclusion of alternative pathology. By itself it is of

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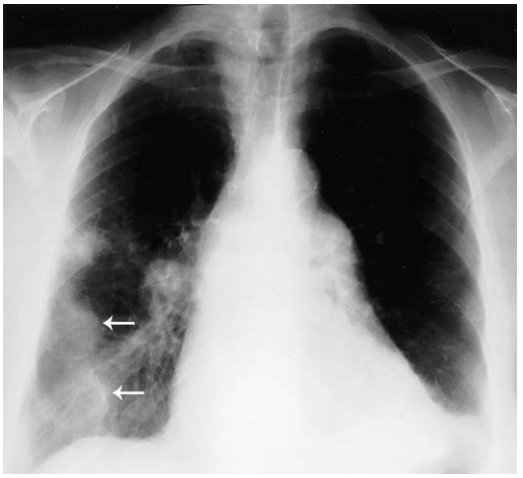

Fig. 1. CXR of a patient who had known PE. Right lower lobe pleural-based opacities (Hampton's hump) represent infarcts (*arrows*). Note dilated pulmonary arteries and bilateral small pleural effusions.

limited value in the diagnosis of PE because of poor sensitivity and specificity.

The Prospective Investigation of Pulmonary Embolism Diagnosis (PIOPED) study was a landmark in the diagnosis of PE, although it was done before the era of CTPA or MRPA. The most common radiographic abnormality is atelectasis, although this finding was equally prevalent in patients who did not have PE. Other signs of PE include enlargement of the main pulmonary artery, pleural effusion (usually small and often unilateral), regional oligemia, and elevated hemidiaphragm (indicating volume loss). The most specific sign was found to be a Hampton's hump, which is an uncommon 3 to 5 cm, pleural-based, pyramid-shaped opacity that usually indicates pulmonary infarction (Fig. 1). Thus, the radiographic signs of PE are highly nonspecific (eg, atelectasis or pleural effusion) or even absent altogether. In this study 12% of 383 patients who had PE had *normal* CXRs [11].

Thus, the main role of the CXR is to exclude obviously unrelated causes of similar symptoms such as pneumothorax, displaced endotracheal tube (ET) tube, mucous plugs, and so forth. A high-quality postero-anterior (PA) and lateral study is always preferred when possible. The CXR also stratifies the patient's potential suitability for a V/Q scan.

Ventilation–perfusion scintigraphy

Until recently, V/Q scans were used extensively as the primary imaging method for evaluation of suspected PE. In this test, radiolabeled albumin aggre-

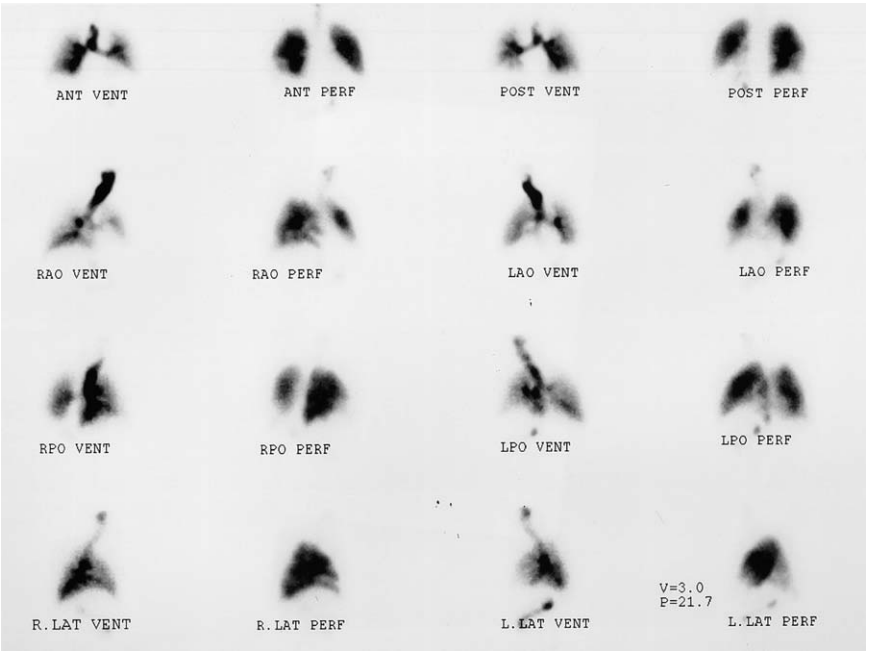

Fig. 2. V/Q scan with high probability of pulmonary embolus—bilateral multiple perfusion defects, all of which mismatch on ventilation. PE was confirmed by CTPA (see Fig. 6).

gates are injected and carried to capillary beds in the lung, where they lodge. Their absence from a particular portion of lung suggests that the pulmonary artery branch to that region might be occluded. Similarly, images of an inhaled radioactive gas provide ventilation imaging, giving the interpreting physician a view of abnormally ventilated lung regions (Fig. 2). Classically, a PE will manifest as a V/Q mismatch with a segmental region of low perfusion but normal ventilation. A normal or near-normal V/Q scan by itself has a high negative predictive value (NPV), essentially excluding PE (<5% probability); a high probability scan is also widely regarded as diagnostic (>90% positive predictive value). It is also widely available, and most radiologists have had extensive experience with it. A current CXR is required for interpretation of a V/Q scan; however, V/Q scanning is most often nondiagnostic (in 73% of patients in the PIOPED study) [11]. As many as 90% of patients who have underlying lung disease have neither normal nor high probability studies. An indeterminate V/Q scan is nondiagnostic (probability 10–90%). A low probability V/Q scan *does not* rule out PE. In the PIOPED study, 14% of patients who had low probability V/Q scans had angiographic evidence of PE. Moreover, not every surgical patient can cooperate with the ventilation portion of the study, and critically ill patients might not be well served by the 1 hour or more of imaging in the nuclear medicine department that is needed for the test.

A V/Q scan is an appropriate first test for evaluating a patient who has suspected PE only when the baseline CXR is normal and the pretest clinical suspicion is low or moderate. In these patients a normal result will frequently be obtained without the use of iodinated contrast or the somewhat higher radiation dose of CTPA; however, in many patients—especially when the baseline CXR is abnormal or there is history of significant underlying pulmonary disease—a V/Q scan might not provide the necessary information to diagnose or exclude PE.

Conventional angiography

CA gives nondiagnostic results in only 3% of patients and it has been shown to have a 99.4% NPV by clinical follow-up; however, it is invasive and carries a 0.5% mortality rate associated with the study itself, most commonly in intensive care unit patients [12]. The traditional reliance on CA as the gold standard has recently been questioned because of its inability to detect subsegmental emboli consistently. Interobserver agreement for diagnosing subsegmental emboli using the supposed gold standard, pulmonary angiography, is about 66% [11].

Venous imaging

Deep vein thrombosis (DVT) and PE are separate manifestations of the same disease process. DVT can be detected in 50% of patients who have angiographically proven PE. Because the treatment of these conditions is similar, the presence of DVT justifies anticoagulant therapy and therefore obviates a search for a pulmonary artery clot [13]. This test does not directly detect PE itself; the source of PE can be identified pathologically in the lower extremity venous tree in only 59.4% of patients [14]. In patients suspected of having PE, only 29% of duplex ultrasonography (US) will be abnormal at the time of presentation [15]. At autopsy, no thromboembolic source could be detected in 28% of patients who died of PE, suggesting complete dislodgement of thrombus from an unknown source [14]. A non-lower extremity or completely dislodged embolus would lead to a negative lower extremity venous study despite the presence of PE of any size.

Duplex US [16] is the imaging method of choice for evaluating DVT. It has a sensitivity of 91% and specificity of 99% [17]. The sensitivity for diagnosis of femoral DVT approaches 100%. Duplex scans are less sensitive for isolated calf vein thrombosis and will not detect iliac vein thrombosis. Duplex US should always be done in both legs in patients who have suspected DVT because of the high incidence of asymp-

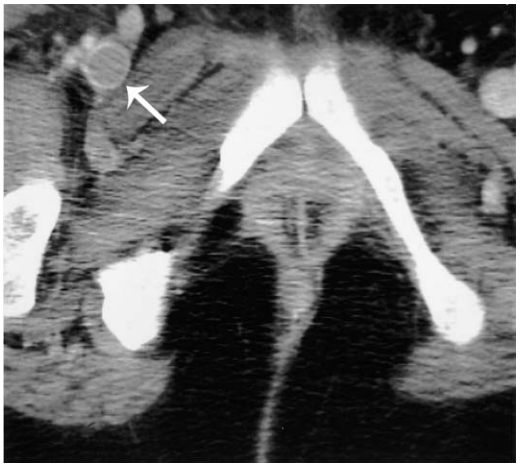

Fig. 3. Combined CTPA–CT venography at groin level shows a thrombus in the right femoral vein (*arrow*).

tomatic DVT in the contralateral leg, even when the ipsilateral leg has no DVT by duplex US [18].

At some institutions, cross-sectional imaging of the venous system is performed (Fig. 3). More commonly, indirect CT venography is performed immediately after CTPA using venous enhancement from the pulmonary artery contrast bolus itself. Loud and colleagues [19] demonstrated a sensitivity of 99% and a specificity of 100% for femoropopliteal DVT using CT venography. In another study comparing indirect CT venography to US, all 15 cases of DVT identified on US were detected on CT, plus four additional cases not identified on US [20]. Other studies have also shown excellent results [21]. Moreover, these methods can study the iliac system, most of which is inaccessible to US. Indirect techniques represent one-step imaging for PE and DVT and only require a few extra minutes of imaging time [22].

The former gold standard test for lower extremity DVT, conventional venography, is an invasive procedure and is now rarely used for the primary evaluation of DVT. The many potential complications of venography include development of DVT.

CT pulmonary angiography

With the introduction of spiral CT scans in the early 1990s, and then with the introduction of multidetector scanners in the late 1990s, it has become possible to image the entire chest in a short time and in a single breath-hold. CTPA visualizes PE directly as filling defects within contrast-opacified pulmonary arteries. Unlike other techniques for visualizing PE, it also provides an excellent study of the lung parenchyma and pleura. Like CA, the test involves the use of a moderate radiation dose and the exposure to iodinated contrast media, but it does not require invasive catheterization; however, the technique can be quite sensitive to respiratory motion during imaging, often an issue with patients who are dyspneic or ventilated.

The first major comparison of CTPA to the gold standard of CA sparked tremendous interest in the technique [23]. Remy-Jardin and colleagues compared spiral CTPA to CA in 42 patients. In the

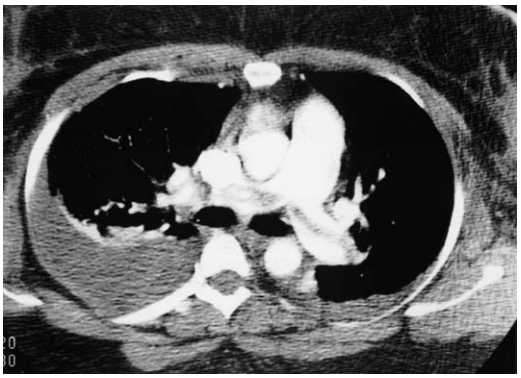

Fig. 4. Massive central PE. CTPA at the level of main pulmonary artery shows a large filling defect extending to the left and right pulmonary trunks.

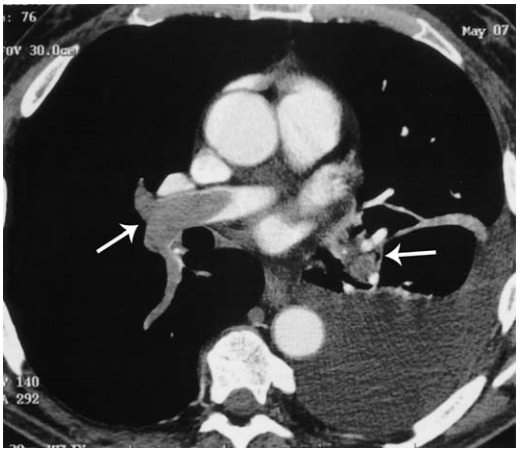

Fig. 5. Bilateral central PE. CTPA at the level of right pulmonary trunk shows filling defects in right main and left descending arteries (*arrows*).

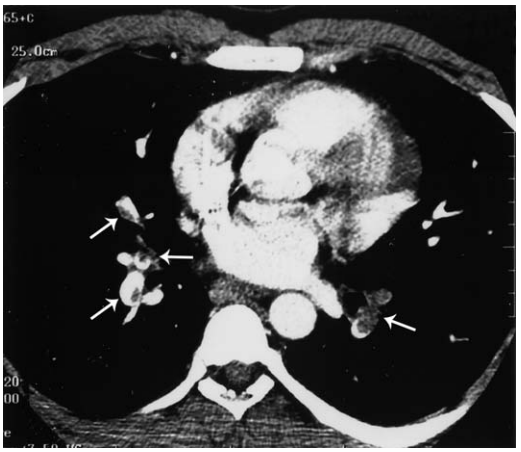

Fig. 6. Bilateral lobar and segmental PE. CTPA shows filling defects in right middle lobe artery and multiple lower lobe segmental arteries (*arrows*). For V/Q scan on the same patient see Fig. 2.

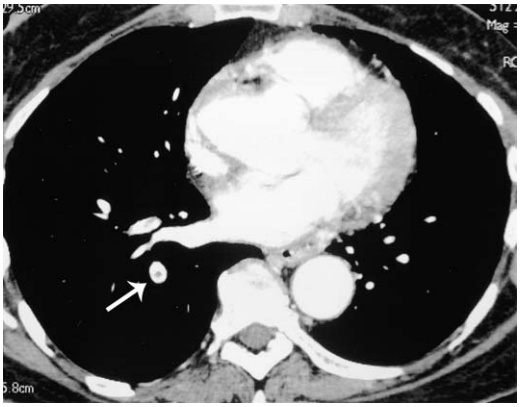

Fig. 7. Segmental PE. CTPA at the level of lower lobes shows a filling defect in right posterior segmental artery (*arrow*).

19 patients who showed central PE, 18 were confirmed by pulmonary angiography, with an overall sensitivity of 100% and specificity of 96%. In 1993 Teigen et al [24] used electron beam CT to evaluate PE. They studied 86 patients and found similar results, with a sensitivity of 95% and specificity of 80%. These early reports showed the ability of CT to demonstrate emboli in the main, lobar, and segmental branches of the pulmonary arteries (Figs. 4–8, respectively); however, the accuracy of detecting subsegmental clots was considerably low. In 1995 Goodman et al [25] found that the sensitivity and specificity for detecting thrombus in the central vessels using helical CT were 86% and 92%, respectively; however, when subsegmental arteries were included the sensitivity was only 63%. Other studies have found similar results [26].

Although spiral CT is quite accurate in detecting more central PEs, it has demonstrated limited value in the diagnosis of subsegmental emboli. The prevalence, detection, and significance of these emboli are controversial. In a prospective study that included 130 patients who had PE, 22% of patients had no larger than a subsegmental clot [27]. Other studies showed a 5.9% [28] or a 30% [29] prevalence of PE limited to subsegmental vessels. Baile et al found no difference between spiral CT and pulmonary angiography for detection of subsegmental PEs when they injected methacrylate beads in pigs [30]. Rapid technical advances in CT techniques and machinery are increasing the detectability of smaller clots. Using 1.25 mm CT sections, one group found that 94% and 74% of subsegmental fourth order and fifth order vessels, respectively, could be evaluated adequately [31]. Other studies have shown benefit from thinner sections [32] and multidetector machinery [33]. These techniques and equipment are rapidly propagating through radiology departments.

Even after diagnosis of isolated subsegmental emboli is established (Fig. 8), the clinical significance of the finding is unclear. Patients who have limited cardiopulmonary reserve might be at increased risk from even a small PE. Also, a small PE can be significant when it is a sentinel event preceding a larger embolus (ie, when there is a large residual DVT burden at the originating site of the embolus). In patients who have PE there is a correlation between patient outcome and residual clot burden at US. The practical concern is that missed subsegmental emboli could result in a poor outcome in patients who have false-negative CTPA who are not anticoagulated.

This issue has been studied extensively with outcome-based studies of patients *not* anticoagulated after a negative CTPA. These reports, summarized in Table 1, have consistently found an NPV of greater than 94% when measured against clinical follow-up in the absence of anticoagulation. Most of these studies have concluded that terminating the imaging sequence after an adequate negative CTPA appears to be safe [34–39], although some of these patients also had negative Doppler studies. Only one large study did not agree with these conclusions, at least for high-risk patients, although they also had an NPV of at least 94.7% [40]. This same study also found that in a subset of 12 patients who had negative Dopplers and isolated subsegmental PE on CTPA, nine patients had negative V/Q scans or CA and did well clinically without anticoagulation [40]. Finally, a large prospective comparison study found that the NPV of a negative CTPA (99% in that study) was statistically

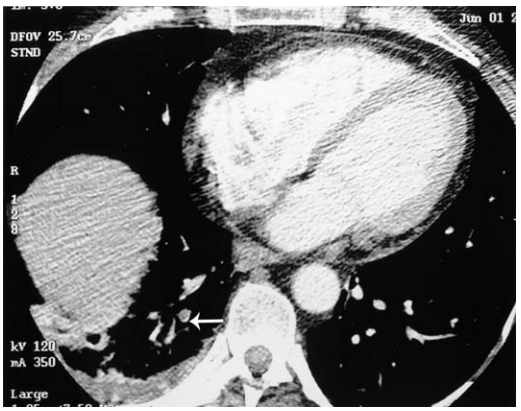

Fig. 8. Isolated subsegmental PE. CTPA at the level of lung bases shows a filling defect in a small subsegmental artery of medial basal segment of right lower lobe (*arrow*).

Table 1
Studies withholding anticoagulation after negative CT pulmonary angiography

No. patients	NPV (%)	Clinical follow-up (mo)	Other patient qualifications	Ref.
100	100	6		[34]
71	96	6	Nondiagnostic V/Q scans	[35]
215	98.6	3		[36]
993	99.5	3	Patients studied by electron beam CT, not helical CT; retrospective	[37]
81	95.1–97.5	21 (avg)	Negative Dopplers	[38]
198	99	3		[39]
507	98.2	3	Negative Dopplers	[40]
			Low or intermediate clinical suspicion	
75	94.7	0[a]	Negative Dopplers	[40]
			High clinical suspicion	[41]

[a] These patients were studied immediately by V/Q or CA.

similar to a normal V/Q study (100% NPV) [39]. The large preponderance of evidence suggests that withholding anticoagulant therapy after negative CTPA appears to be safe. In retrospect this might not be surprising given the excellent NPV of CA itself despite its poor interobserver agreement regarding subsegmental clots. CA should continue to be used for the approximately 10% of CTPA studies that are nondiagnostic.

Another advantage of CTPA over other studies is that it provides excellent evaluation of secondary signs of PE such as infarction, pulmonary artery dilatation, atelectasis, and pleural effusion. Infarction can be differentiated from atelectasis by its lack of enhancement (Fig. 9).

In addition to its usefulness for diagnosing or excluding PE, CT gives unparalleled evaluation of the lung parenchyma. Studies of CTPA reported alternative diagnoses by CTPA in 39% to 67% of patients who did not have PE [41,42]. The alternative diagnoses found in these studies included pneumonia, cardiac or pericardiac disease, interstitial lung disease,

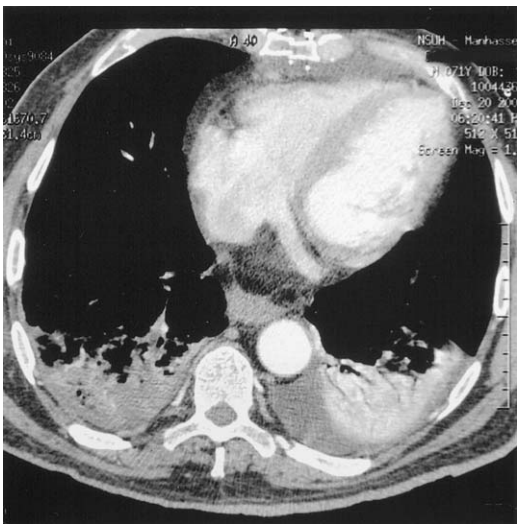

Fig. 9. Infarction versus atelectasis. CTPA at the level of lung bases in a patient who had PE shows a pleural-based, nonenhancing opacity in right lower lobe (infarct) and an enhancing opacity in the left lower lobe (atelectasis).

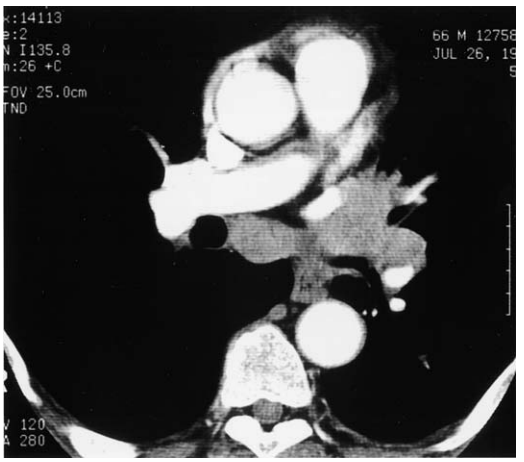

Fig. 10. Alternate diagnosis: lung cancer. Sixty-five-year-old man who had shortness of breath and hemoptysis. V/Q scan showed high probability for PE. CTPA showed a left hilar mass and mediastinal adenopathy with no evidence of PE.

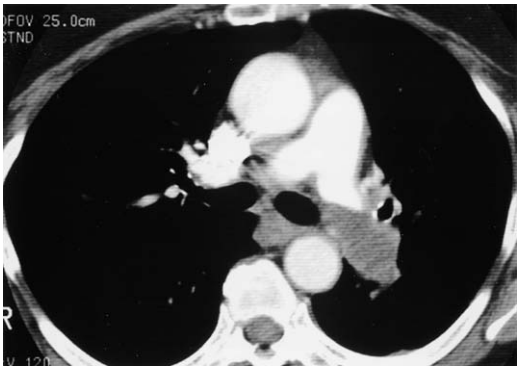

Fig. 11. Alternate diagnosis: pulmonary artery angiosarcoma. Sixty-eight-year-old woman who had shortness of breath and cold substernal sensation while playing tennis. V/Q scan showed intermediate probability for PE. CTPA showed a filling defect in left pulmonary artery with distension of the lumen. Biopsy of left lower lobe nodule (not shown) revealed angiosarcoma.

malignancy, pleural effusion, and mediastinal mass (Figs. 10–12).

The ever-increasing speed of multidetector CT now allows for repeated scanning through the hila during the course of the contrast bolus. A graph of enhancement versus time allows for measurement of functional tissue perfusion is reminiscent of nuclear perfusion imaging but with specific anatomic detail [43] that might, in turn, give important information regarding patient management.

Magnetic resonance pulmonary angiography

MRPA, the "other" cross-sectional imaging technique, can be of use as an adjunctive technique in selected surgical patients. Like CTPA, the test directly detects the presence of emboli as filling defects in contrast-labeled pulmonary arteries; however, MRPA relies on completely different physical principles (nuclear magnetic resonance rather than x-ray scattering) for image formation. Advantages of MRPA include lack of ionizing radiation and the relatively low incidence of renal and allergic complications from gadolinium chelates [44], which facilitates imaging of particularly radiation-sensitive patients such as pregnant women and patients who are allergic to iodinated contrast or who suffer from renal insufficiency; however, MRPA is a longer, more complex, and expensive test than CTPA, and its availability and practicality vary widely.

Efficacy of modern gadolinium-based MRPA is comparable to CT for segmental and larger emboli. In a porcine model study involving 42 PEs, MRPA and CTPA were found to have similar sensitivities (82% versus 76%, respectively) and positive predictive values (94% versus 92%) using a pathologic gold standard [45]. Human studies comparing gadolinium-based MRPA to a digital subtraction angiography (DSA) gold standard are summarized in Table 2. False-positives are uncommon, with specificity reported as greater than 95% in all studies. Sensitivity ranged from 68% to 100%; sensitivity for smaller emboli was lower in all studies in which this discrimination was made. The largest single study [46] reported a sensitivity of only 40% for isolated subsegmental PEs compared with 84% for segmental and 100% for lobar or central PEs. Furthermore, outcome-based studies following patients who had negative MRPA (eg, those summarized in Table 1 for CTPA) have not yet been performed for MRPA. Like CTPA, a positive MRPA is a solid basis for treatment; however, a negative MRPA does not exclude the possibility of small PEs, and no adequate trials have demonstrated the safety of withholding anticoagulation on the basis of a negative MRPA.

Other barriers arise frequently when considering MRPA. Critically ill patients who have many lines and monitors can be difficult to place and adequately monitor inside a magnet bore. Patients who have surgical materials such as ferromagnetic aneurysm clips or pacemakers must not enter an MRI facility. These and other patients are not candidates for MRPA [47,48]. Also, unlike CTPA, MRPA provides little information about the lung parenchyma, so it has a

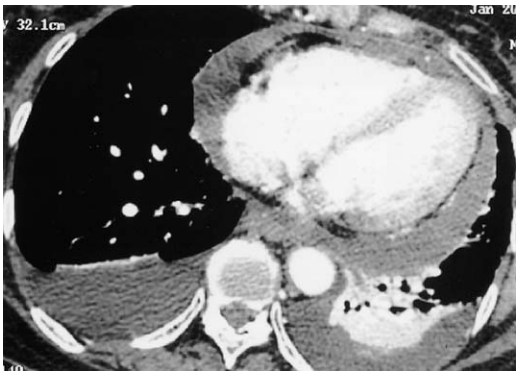

Fig. 12. Alternate diagnosis: pleural and pericardial effusion. Sixty-year-old woman who had shortness of breath and chest pain. rule out PE. CTPA showed no evidence of PE.

Table 2
Comparison studies of magnetic resonance angiography and digital subtraction angiography (DSA)

Emboli	Sensitivity (%)	Specificity (%)	Distal evaluation	Ref.
22	100	95	No subsegmental emboli reported on DSA	[52]
19[a]	68	99.7	Missed 4/6 subsegmental PEs	[53]
61	82	98	Missed 6/16 subsegmental PEs	[48]
19	70	100	All 6 distal PEs missed	[50]
Range	68–100	95–100		

Each study compared gadolinium-enhanced MRA with conventional DSA, using conventional DSA as the gold standard.
[a] All patients in this study had initial nondiagnostic V/Q scans.

greatly reduced ability to provide alternative diagnoses. Health system barriers such as availability of magnet time, state-of-the-art MRI hardware, local radiologist expertise, and the considerable cost of the study must be considered in the decision to order the test.

MRPA, like CTPA, continues to evolve and improve. Early methods used mostly spin-echo or time-of-flight techniques and were limited by flow artifacts and long imaging times, precluding breath-hold images (see [49] for a review). These techniques are often still used as supplemental imaging sequences, but MRPA in nonpregnant patients now usually involves administration of intravenous gadolinium as a contrast agent. These methods, pioneered in humans by Loubeyre and colleagues [50], increase visibility of the distal arterial tree, especially when done using breath-hold methods. Using state-of-the-art equipment, some MRPA techniques can now be accomplished in as little as 4 seconds [51].

In summary, MRPA is a useful method for ruling in a PE in selected patients who have contraindications to CTPA. A positive MRPA is specific for PE and thus appears to be sufficient basis for treatment; however, a negative MRPA does not fully preclude PE in the context of high clinical suspicion. The practicality, cost, and poor visualization of the lung parenchyma with MRPA must also be factored into the decision to order the test.

Imaging algorithm

Imaging studies form the mainstay of the diagnosis of PE. The official position of the American Thoracic Society, as adopted in 1999, states the matter well: "The history, physical examination, chest radiograph, electrocardiogram, and arterial blood gas analysis…by itself…is inadequate to confirm or exclude the diagnosis of PE" [52].

The natural history of PE combined with knowledge of available modalities' strengths and weaknesses forms the basis for an imaging algorithm that is appropriate for surgical patients. In all patients, the initial imaging study should be a high-quality CXR. A study including PA and lateral views is preferred, although often only an antero-posterior (AP) view is possible. The presence of an obviously unrelated nonthrombotic explanation for the patient's symptoms (eg, pneumothorax, mucus plug, dislocated ET tube, and so forth) should lead to appropriate treatment. Further imaging directed toward embolic disease is then only pursued if symptoms unexpectedly persist.

Most surgical patients should then be considered for CTPA as shown in the authors' proposed algorithm (Fig. 13). CTPA has repeatedly been shown to be an effective first-line test for PE. It can be obtained rapidly at most centers and it is diagnostic much more often than V/Q scanning [53,54]. CTPA has been found to be more sensitive and specific overall in at least one direct prospective comparison of the two procedures as the initial test [53]. When CTPA is nondiagnostic, consideration should be given to conventional pulmonary angiography, keeping in mind the additional cumulative load of contrast dye.

V/Q scanning is appropriate as the initial test in low- or intermediate-risk patients who have scrupulously normal PA and lateral CXRs. In these patients the V/Q scan is often normal, which excludes the presence of PE without the risk of iodinated contrast material. If findings are equivocal, the algorithm should continue with CTPA or MRPA. Patients who had abnormal CXRs who are not candidates for CTPA (eg, patients who have renal insufficiency [typically Cr >1.5 mg/dL] or severe allergy to iodinated contrast media) should be considered for MRPA. Although this test has limitations and contraindications as mentioned previously, a positive MRPA is a solid basis for treatment (Table 2) and allows the diagnosis of PE to be made without ionizing radia-

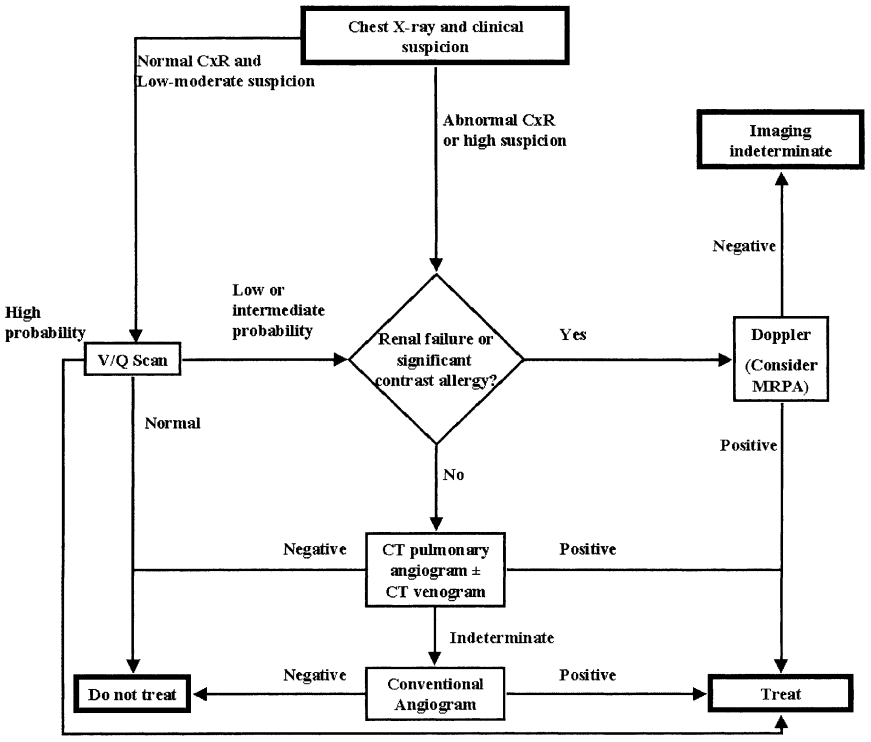

Fig. 13. Imaging algorithm.

tion or iodinated contrast media. MRPA also often allows for the establishment of alternative diagnoses and simultaneous venous study, although it is not as effective at evaluating lung parenchyma as CT. A negative MRPA is not an adequate basis for withholding treatment.

The role of venous imaging is somewhat complex. Doppler imaging of the legs does not detect PE directly, and it is neither sensitive nor specific for the condition; however, the presence of DVT puts the patient at risk for PE even if one has not yet occurred, and anticoagulation is indicated for the DVT alone. Anticoagulation usually obviates further imaging for detection of PE itself. If the clinical question is "has the patient suffered a pulmonary embolus?" then lower extremity imaging is indicated only when direct tests for PE cannot be done, and this is how the authors' algorithm (Fig. 13) was designed. If the question is "would the patient benefit from anticoagulation?" then it would be reasonable to perform a venous imaging study even when a PE has been ruled out by CTPA, V/Q, or CA because even a DVT that has not embolized generally deserves anticoagulation. If desired, CT or MR venography can be performed at the same time as CTPA (MRPA) without additional contrast media and with little additional radiation (in the case of CT).

Caution should be used when relying on venous imaging to guide treatment. A negative Doppler alone does *not* exclude PE. The decision to treat inpatients who cannot leave the Surgical Intensive Care Unit (SICU) for V/Q, CTPA, or MRPA but who have negative Dopplers must be based on d-dimer, CXR findings, and clinical judgment alone. Patients treated for PE on the basis of venous imaging alone should be reevaluated, when possible, to confirm the diagnosis, thus ensuring that the patient's symptoms are not caused by another undetected condition masquerading as PE. Under these circumstances a negative confirmatory study for PE would not negate the need for anticoagulation for the DVT.

The exception to the rule of imaging diagnosis of PE is the case of massive PE. Eleven percent of patients who have PE die within 1 hour of presentation from systemic collapse caused by increased right heart strain and acute pulmonary hypertension leading to cardiovascular collapse [55]. Presentation of these patients is often dramatic, and treatment (thrombolysis or thrombectomy) is different than for the majority of patients who have submassive PEs. TEE can be used

to investigate patients who have sudden acute shock and appropriate physical signs, followed immediately by thrombolysis if a central PE is found [56]. TEE can also be used to assess for indirect signs (see [55] for a review of these cases and their management).

Thus, each imaging modality has a role in the diagnosis of PE. Normal V/Q, CA, or CTPA appear to be adequate for withholding treatment, whereas high-probability V/Q or positive MRPA, CTPA, or CA appear to be specific. MRPA can be used when CTPA is contraindicated, and V/Q scanning is still useful for low- or intermediate-risk patients or patients who have contrast allergy and contraindication to MRPA. Lower extremity venous studies are neither sensitive nor specific but can be done portably, whereas TEE can detect some large central emboli quickly. For most surgical patients, however, CTPA appears to be the first and only advanced imaging modality needed to diagnose or exclude PE.

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