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Multislice CT of Venous Thromboembolic Disease: Pulmonary Embolism and Deep Venous Thrombosis

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LEARNING OBJECTIVES

Upon completion of this activity, participants should be able to:

- Describe the correct technique for performing CT pulmonary angiography using multislice CT scanners (MSCT).
- List the imaging findings of acute and chronic pulmonary embolism (PE) on CT pulmonary angiography and discuss the interpretive pitfalls in the diagnosis of PE on CT.
- Discuss the role of postprocessing methods for visualization of the pulmonary arteries; recognize their value and limitations.
- Compare the clinical utility of MSCT for the detection of PE with other imaging modalities, such as conventional catheter angiography and ventilation/perfusion scintigraphy.

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Pulmonary embolism (PE) is a life-threatening disease that affects up to 200,000 patients annually in the U.S.^{1,2} Acute pulmonary embolism is the third most common cause of cardiovascular death after myocardial infarction and stroke.⁴ Prompt and accurate diagnosis with institution of anticoagulant therapy reduces patient mortality from 30% to between 2% and 10%.⁵ The majority of preventable deaths due to PE can be ascribed to missed diagnosis rather than a failure of existing therapies.

The clinical presentation and routinely available bedside and laboratory data, such as blood gas analysis, electrocardiography, and chest radiography, cannot be used to either confirm or exclude the diagnosis of PE. The measurement of a degradation product of cross-linked fibrin, such as D-dimer, is a sensitive but nonspecific screening test for suspected venous thromboembolism. The diagnosis relies heavily on imaging, and in daily clinical practice multislice CT (MSCT) has practically become the first-line modality for imaging the pulmonary arterial circulation in patients with suspected PE. MSCT scanners enable volumetric data acquisition with narrow collimation and fast scanning times, thereby improving visualization of the peripheral pulmonary arteries.

MSCT PULMONARY ANGIOGRAPHY TECHNIQUE

The key to effective MSCT scanning for PE is careful attention to technique. Multiple studies have shown that

the thinner the collimation, the better the depiction of the smaller peripheral arteries.^{6,8} To optimize visualization of the subsegmental arteries, the study should be performed at the thinnest slice thickness achievable in a single inspiratory breath-hold, minimizing respiratory motion artifact. We use 130 to 150 mL of 300-mg iodine/mL low-osmolar contrast material injected through an 18 to 20-gauge intravenous line placed in an antecubital vein. Intravenous contrast media is injected at a rate of no less than 4 mL/sec. The time to peak pulmonary artery enhancement following injection of contrast at the rate of 4 mL/sec is approximately 20 to 25 seconds. This may be used empirically as the scan delay time in patients with normal cardiac function. A saline chaser bolus is ad-

vocated to reduce the total contrast volume and eliminate streak artifacts from high-density contrast in the superior vena cava. Scanning in a caudocranial direction provides some reduction of the latter. In patients with poor cardiac reserve, a timing bolus may be used to determine the time to peak arterial enhancement. Scanning in the caudocranial direction also minimizes breathing artifacts late in the acquisition sequences, which are less significant should the

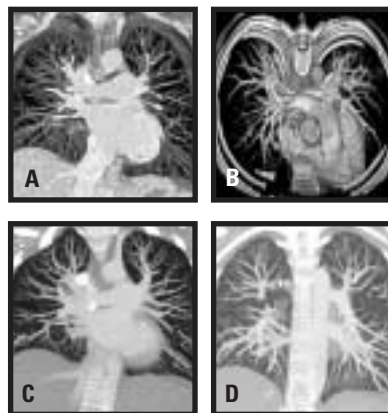


Figure 1. Normal pulmonary arteries in a 24-year-old woman with chest pain. Patient is an oral contraceptive user. A 64-slice MSCT examination covers the entire chest within four seconds, allowing visualization of even the most peripheral pulmonary vessels with exquisite detail. A: Coronal volume-rendered technique. B: Volume-rendered technique viewed from above. C and D: Coronal maximum intensity projections.

patient exhale while his or her upper lobes are being scanned.

CT venography can be accomplished readily after acquisition of the thoracic portion of the examination without requiring any additional intravenous contrast media. Incorporating CT venography with the CT pulmonary angiography study ensures that the pulmonary arteries and lower extremity veins are imaged sequentially in one study, and increases the diagnostic yield for venous thromboembolism from PE alone to include patients with both PE and deep venous thrombosis, as well as patients with isolated DVT.

INTERPRETATION OF MSCT FOR PE

- *Using a workstation.* Accurate interpretation requires using a computer workstation rather than hard-copy printed film. Soft-copy viewing has been shown to both reduce interpretation time and increase diagnostic accuracy; sensitivity for detecting emboli in smaller arteries in particular is improved.⁹ It not feasible to print the large number of reconstructed images acquired when using MSCT scanners. Cine-mode viewing of images on a workstation allows tracing of entire vessels from the central pulmonary arteries at the hila to the periphery. Veins and mucus-filled bronchi can be easily differentiated from arteries, the former connecting to the left atrium and the latter to the central airways. In addition, the window width and levels can be quickly and appropriately adjusted for optimal viewing of the pulmonary vessels and lung parenchyma.

- *MSCT findings of acute PE.* The diagnosis of PE on MSCT hinges on the direct visualization of emboli. In essence, this is a pulmonary angiogram performed with a CT scanner instead of a fluoroscopic unit. Specific findings are filling defects that completely occlude a well-enhanced pulmonary artery (vessel cutoff sign), with or without visualization of the distal nonopacified artery, and a partially occluded artery with a surrounding rim of contrast identified as the "rim sign" when seen in short axis or the "railway track" sign when seen in long axis. A diagnosis of PE should not be made if an unopacified artery is visible on only one thin-section axial image, as this may result from vessel pulsation. Most patients with pulmonary emboli also have a visible pulmonary parenchymal or pleural abnormality on CT.^{10,11} However, the only lung abnormality with a high specificity for PE is a focal area of consolidation adjacent to a pleural surface that is wedge-shaped or has convex borders bulging toward the hilum; in other words, a pulmonary infarct.^{10,11} Subsegmental atelectasis, focal oligemia, and small pleural effusions are common in many conditions other than PE, and have no predictive value for PE.

- *MSCT findings of chronic PE.* Chronic PE tends to be eccentric and contiguous with the vessel wall, appearing as mural thickening. There may be recanalization within a thrombus, which produces arterial stenosis or webs.¹² Less commonly, chronic

thrombi may calcify. Abrupt narrowing of vessel diameter and cutoff of distal lobar or segmental arteries may be observed. Additional diagnostic findings of chronic PE include enlargement of the central pulmonary arteries and the presence of dilated and tortuous bronchial arteries, particularly if secondary pulmonary arterial hypertension has developed.^{13,14} A mosaic lung attenuation pattern, consisting of localized areas of decreased and increased attenuation due to regional alterations in pulmonary blood flow may be seen with chronic PE; however, it may also be seen with infiltrative lung diseases and small airway diseases. Expiratory scans may help to distinguish whether the mosaic pattern is caused by chronic PE or small airway disease. A lack of air trapping on end-expiration favors chronic PE over airway disease.¹⁵ Note, chronic PE may lead to ipsilateral proximal bronchial dilatation and air trapping on CT as well.¹⁶

- *MSCT findings of DVT.* The diagnostic findings of acute DVT on CT venography include low-attenuation intravascular filling defects and complete lack of enhancement of a venous segment.¹⁷ Ancillary findings include enlargement of the thrombosed vein, venous wall enhancement, and perivenous edema. In chronic DVT, the affected vein is often smaller than the adjacent artery, may be calcified, and may not carry any contrast-enhanced blood. Extensive collateral veins may also be observed.

- *Pitfalls in PE diagnosis on MSCT.* Pitfalls in the diagnosis of PE with MSCT can be divided into technical and interpretative pitfalls.¹⁸ Technical pitfalls include patient motion artifact, suboptimal contrast enhancement, image noise in obese patients, and streak artifact from high-attenuation structures. Interpretative pitfalls include vessel bifurcations producing the appearance of a peripheral or central lucency, perivascular lymphatic tissue producing the appearance of a peripheral intravascular filling defect due to volume averaging, and mucous plugging of bronchi misinterpreted as occluded pulmonary arteries. Important strategies for avoiding pitfalls include meticulous technique, an understanding of normal anatomy, and interactive interpretation at a workstation.

ADVANCES OF MSCT FOR PE DETECTION

The introduction of MSCT scanners of increasing detector rows and faster gantry rotation speeds has improved the spatial resolution of MSCT. Shorter scan times result in fewer patient motion artifacts and reduced contrast requirements. The improvement in spatial resolution allows evaluation of pulmonary arteries down to sixth-order branches, and significantly increases the detection rate for segmental and subsegmental PE, as well as increasing interobserver agreement for the detection of PE.^{6,8} Multislice CT can be used to decrease overall scan time by increasing the table speed and using simultaneous data acquisition with multiple detectors. Faster scanning allows the entire thorax to be scanned in a single breath-hold even in patients

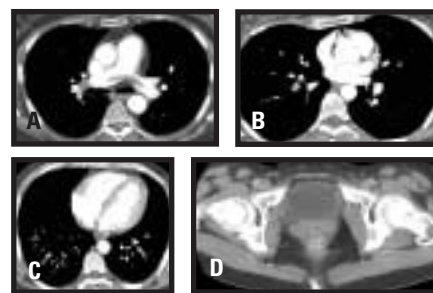


Figure 2. Acute bilateral pulmonary embolism with right lower extremity deep venous thrombosis. A: Saddle embolus across the bifurcation of the main pulmonary artery. B: Embolus in the right lower lobe proximal pulmonary artery seen in cross section surrounded by contrast. C: Lateral-basilar segmental artery embolus in the left lower lobe. D: Thrombus in the right common femoral vein.

with dyspnea. With 16-row MSCT, scan time is less than 10 seconds. With 64-row MSCT scanners, the acquisition time is three seconds. The faster scan time of MSCT has several advantages over single-slice CT including increased length of coverage in a single breath-hold, ability to use less intravenous contrast, improved consistency of enhancement throughout the imaging volume, and decreased respiratory and cardiac motion. The improvement in image quality achieved through fewer motion artifacts on MSCT scans has been shown to increase the diagnostic accuracy of CT angiography, particularly for patients with impaired respiratory function.¹⁹

State-of-the-art MSCT with 16 or more detector rows allows for isotropic imaging in which the voxels that make up the volumetric data set are cuboid; that is, they are the same size in all dimensions. With isotropic imaging, postprocessing of nonaxial reformatted images with a resolution comparable to axial images is possible. All of the published accuracy data on CT for PE have used

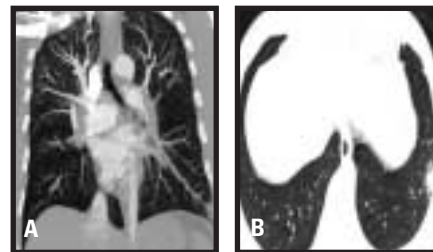


Figure 3. Acute pulmonary embolism with pulmonary infarction. A: Coronal maximum intensity projection demonstrates an embolus in the main pulmonary artery extending into the left lower lobe artery, with a wedge-shaped peripheral parenchymal opacity in the left lower lobe representing an infarct. B: The infarct as seen on axial-section lung windows.

axial CTA. However, it may be possible to improve accuracy or diagnostic confidence using supplemental viewing methods. For example, arteries coursing oblique to the axial plane may be more readily assessed with reformatted images perpendicular or parallel to the long axis of the artery. In a small group of patients with inconclusive axial spiral

CT done at 3-mm collimation, 2D reformatting enabled confident exclusion of central pulmonary embolism.²⁰ Coronal multiplanar reformatted images readily display the perilymphatic tissue, which may cause false-positive interpretations.²¹ The use of 3D shaded-surface display reconstructions in addition to thin-section axial overlapping sections may allow a greater proportion of segmental and subsegmental arteries to be identified compared to axial overlapping thin sections alone.²² Recently, a new image display method called “the paddlewheel technique” has been described. A set of planar slabs is arranged in a paddlewheel, or rotational, pattern that pivots on a central horizontal axis between the lung hila.²³ The paddlewheel reformatting technique requires fewer images and provides a continuous display of branching vessels that radiate from both hila. In preliminary studies the paddlewheel method did not result in improved accuracy for detection of proximal PE compared with that of axial CT; however, it may be used for problem-solving or adding diagnostic confidence.

Computer-aided detection systems are being developed and investigated as a means of improving sensitivity for the detection of small peripheral PE. The detection methods are based on segmentation of pulmonary vessels to limit the search space and analysis of several 3D features inside segmented vessel volume. Preliminary studies have demonstrated the feasibility of CAD for PE detection.²⁴⁻²⁸ Larger studies are under way to test the reliability and robustness of the technique. Once developed, CAD may be a viable approach to improving the accuracy and efficiency of PE detection in CTA images.

COMPARISON WITH ALTERNATIVE DIAGNOSTIC TESTS

MSCT is an attractive means for establishing a safe, highly accurate, and cost-effective diagnosis of PE. The technique has several advantages over the traditional methods of evaluating PE, such as ventilation/perfusion scintigraphy (V/Q) and conventional catheter angiography. CT can provide an alternative explanation for a patient's symptoms in many cases, and a normal CT has a very high negative predictive value. V/Q scintigraphy has been the primary test for the investigation of suspect PE for several decades. While V/Q scans have a high negative predictive value if normal (4%) and high positive predictive value if there is a high probability result (88% to 96%), a large proportion of studies are low or intermediate in probability, which does not promote diagnostic confidence when deciding whether to treat a patient for PE. In the PIOPED (prospective investigation of pulmonary embolism diagnosis) I study, 73% of V/Q scans fell into this category.²⁹ In a comparative study of MSCT and V/Q scintigraphy, Coche et al demonstrated a significantly higher sensitivity (96% vs. 86%) and specificity (98% vs. 88%) for the diagnosis of PE

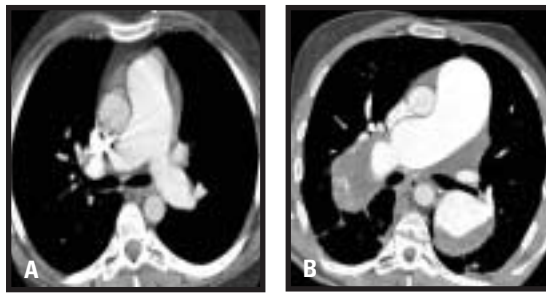


Figure 4. Chronic pulmonary embolism. A: Enlarged central pulmonary arteries with a mural filling defect along the anterior wall of the left main pulmonary artery. B: Markedly enlarged right and left pulmonary arteries with partially calcified chronic emboli.

with CT, using catheter angiography as the gold standard.³⁰ In addition to being more accurate than V/Q scintigraphy, CT provided an alternative diagnosis in 29% of patients without PE. CT also has better interobserver agreement than V/Q scintigraphy.^{31,32} In a recent meta-analysis of the literature, using ROC curve analysis, CT had greater discriminatory power than V/Q scintigraphy at the normal and/or near-normal threshold in the exclusion of acute PE, while CT and V/Q scintigraphy had similar discriminatory power in the diagnosis of PE with a high probability threshold.³³ However, this analysis may have underestimated the test performance of MSCT, as only one MSCT study was included in the analysis. Most of the studies to date have compared CT to V/Q scintigraphy using single-slice CT technology. Reporting on and inclusion of more MSCT studies is expected to verify the modality's improved performance. Compared to V/Q scintigraphy, CT directly visualizes PE; it does not rely on secondary physiologic alterations in perfusion for diagnosis.

Pulmonary angiography, which has long been considered the gold-standard test, is invasive and is associated with a procedure mortality rate of 0.5% and a major complication rate of 1%.³⁴ The interobserver agreement rates for the detection of subsegmental emboli with conventional angiography is low, and its current status as the definitive test is in doubt.^{35,36} A study comparing 1-mm single-slice CT with catheter angiography, using a methacrylate cast of porcine pulmonary vessels as an independent gold standard, found no difference in sensitivity for the detection of subsegmental-sized emboli between the two techniques.³⁷

The authors suggested that with the advent of multislice, CT may surpass the accuracy of catheter angiography. The effective radiation dose with

MSCT pulmonary angiography is less than with digital subtraction angiography (4.2 mSv vs. 7.1 mSv).³⁸

An important advantage of CT over other imaging modalities is that both mediastinal and pulmonary parenchymal structures can be evaluated, so that alternative diagnoses for patients' signs and symptoms can be made. Up to two-thirds of patients in whom there is an initial suspicion of PE receive another diagnosis, including some potentially life-threatening diseases such as aortic dissection, pneumonia, lung cancer, and pneumothorax.^{20,39,40}

As a result of the high-resolution capabilities of MSCT, small peripheral clots limited to the subsegmental arteries that might have gone unnoticed in the past are being detected in patients with minor symptoms. It has been shown that 6% to 30% of patients with documented PE have clots only in subsegmental and smaller arteries.²¹ Controversy exists regarding the treatment of isolated subsegmental emboli. The presence of peripheral emboli may be an indicator of concurrent DVT, thus potentially heralding more serious embolic events. A burden of small peripheral emboli may also have prognostic significance in patients with limited cardiopulmonary reserve and for the subsequent development of chronic pulmonary hypertension. A recent study suggests that patients who receive an MSCT diagnosis of isolated subsegmental PE under certain circumstances (good cardiopulmonary reserve, self-limited risk factors) may not need anticoagulant therapy.⁴¹

Outcome analysis in patients with clinically suspected PE and a negative CT angiogram provides

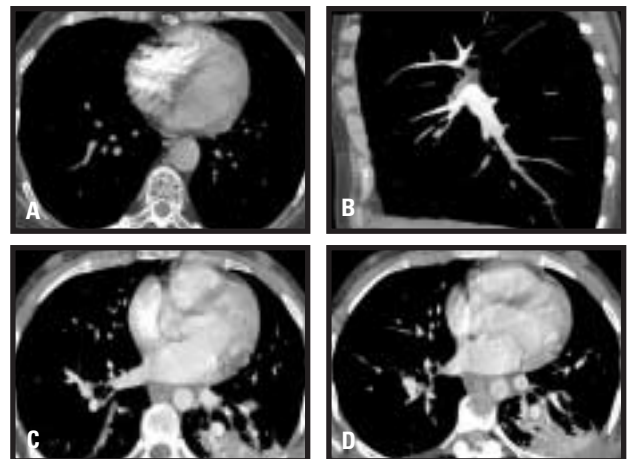


Figure 5. Pitfalls in the detection of pulmonary embolism. A: Poor timing of the contrast bolus simulating nonopacified arteries or filling defects due to pulmonary embolism. B: Sagittal reconstruction in the same patient shows the gradual change in contrast opacification of the pulmonary arteries in the craniocaudal direction. C: Mucus-filled bronchus in the right lower lobe simulating a filling defect due to PE. D: A more cephalad section in the same patient demonstrates a fluid level in a more proximal bronchus in the right lower lobe.

information about the accuracy of the negative test result. Retrospective data on patient outcomes following a negative CT for PE indicate a high

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negative predictive value for a normal study, with reported values as high as 99%.^{19,42,43} In a recent prospective study, the risk of PE at a mean of nine months after a negative MSCT pulmonary angiogram was 1%.³⁹

Combining CT pulmonary angiography and indirect CT venography has become increasingly common, with many institutions worldwide routinely incorporating indirect CT venography into the CT pulmonary angiographic examination. Prospective studies have confirmed that indirect CT venography is similar to sonography in sensitivity and specificity.⁴⁴⁻⁴⁶ Combined CT pulmonary angiography and indirect CT venography has been shown to increase detection of thromboembolic disease by 20% compared with CTA alone,⁴⁷ confirming reports of prior studies that showed similar increased detection rates of 15% to 38%.^{44,48,49} The combination of CT venography and CT pulmonary angiography provides a comprehensive noninvasive imaging

examination for suspected venous thromboembolic disease with a single contrast injection. Like CT pulmonary angiography, CT venography has the potential to provide an alternative, nonvascular, diagnosis for such clinical conditions as an unsuspected pelvic tumor and Baker's cyst.^{50,51}

The accuracy of MSCT in patients suspected of having acute PE is currently being assessed by the PLOPED II study. This prospective multicenter study uses a composite reference test for venous thromboembolism that is based on V/Q scintigraphy, venous compression ultrasound of the lower extremities, digital subtraction angiography, and contrast venography in various combinations to establish the PE status of the patient. The latest results of the PLOPED II study, presented at the 2004 RSNA meeting,⁵² show that with the use of MSCT, a sensitivity of 83% and specificity of 96% can be achieved for the detection of suspected PE. With CT venography added to

CTPA, the sensitivity increased to 90% with specificity of 95%.

CONCLUSION

In daily clinical practice CT has practically become the first-line modality for imaging the pulmonary arterial circulation in patients with suspected PE. Advances in CT technology with the introduction of MSCT scanners have allowed scanning of larger volumes at thin collimation, improving both visualization of segmental and subsegmental vessels and interobserver agreement about the presence or absence of emboli. The isotropic nature of high-resolution MSCT data lends itself to 2D and 3D visualization through a variety of postprocessing techniques. Such methods offer the potential benefit of enhanced display of the pulmonary arteries and improved diagnostic confidence. A normal CT for PE indicates a very low risk of subsequent PE and in many patients without PE, MSCT can provide an alternative explanation for symptoms.

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CME LLC designates this program for a maximum of 1.0 category 1 credit toward the AMA Physician's Recognition Award. Each physician should claim only those credits that he/she actually spent in the educational activity.

The American College of Radiology (ACR) accepts activities designated for AMA Physician's Recognition Award (PRA) category 1 credit.

Florida Residents: CME LLC is registered with CE Broker.com as an approved provider of continuing medical education for Florida-licensed physicians, osteopathic physicians, physician assistants and nurses.

Physician Assistants: The American Academy of Physician Assistants

(AAPA) accepts AMA category 1 credit from organizations accredited by the ACCME

Nurses: The American Nurses Credentialing Center (ANCC) accepts AMA category 1 credit toward recertification requirements. CME LLC is approved by the California Board of Registered Nursing, Provider No. CEP12748, and designates this educational activity for 1.0 contact hours for nurses.

Activities that have been designed for AMA/PRA category 1 credit and are relevant to the radiologic sciences are accepted as category B credit on a one for one basis by the American Registry of Radiologic Technologists (ARRT). Radiologic Technologists may receive a maximum of 12 category B credits per biennium.