# Spiral computed tomography for pulmonary embolism

*Sarah J Howling, David M Hansell*

***Spiral computed tomography pulmonary angiography is increasingly used in the non-invasive investigation of patients with suspected pulmonary embolism. This review will focus on current techniques and indications with an explanation of the computed tomography signs of pulmonary embolism, possible pitfalls in interpretation and limitations of the technique.***

Until the early 1990s, the only imaging techniques available for evaluating the pulmonary circulation were ventilation–perfusion scintigraphy and pulmonary angiography. Since then, improvements in computed tomography (CT) technology, particularly the development of fast scanning techniques and the routine use of automated contrast injectors, have provided optimal conditions for spiral CT pulmonary angiography (SCTPA). Several large studies have shown that SCTPA is effective at demonstrating pulmonary emboli in segmental and larger pulmonary arteries (Remy-Jardin et al, 1996; van Rossum et al, 1996; Mayo et al, 1997). As a result, there is increasing awareness and demand for this imaging investigation. Once initial enthusiasm has been tempered by experience it becomes important to establish:

1. Whether SCTPA is cost effective
2. Where it fits in the diagnostic pathway (i.e. whether it replaces another test or is merely another layer in the diagnostic pathway).

## HISTORICAL BACKGROUND

Although conventional CT has been available for 25 years, the limitations of the single-slice technique, particularly the necessity for patients to hold their breath for each and every slice acquired, meant that the pulmonary arteries were rarely optimally opacified unless an excessive amount of intravenous contrast was used. Reports of pulmonary emboli on conventional CT scans were therefore largely incidental findings on CT scans obtained for other purposes.

It was not until Kalender et al reported the benefits of spiral CT in 1990, that the potential for CT in the diagnosis of pulmonary embolism was realized. Since the pioneering study by Remy-Jardin et al in 1992 there have been seven large studies specifically evaluating the diagnostic accuracy of SCTPA (Senac et al, 1995; Remy-Jardin et al, 1996; van Rossum et al, 1996, 1998; Mayo et al, 1997; Garg et al, 1998; Herold et al, 1998).

## TECHNIQUE

More than most radiological procedures, meticulous technique is a prerequisite as diagnostic accuracy is directly related to the quality of the images. SCTPA is possible in part because of the rapid data acquisition time, which allows uniform, intense vascular opacification during the examination.

SCTPA is ideally preceded by conventional non-contrast CT scans through the entire thorax. Such images may show secondary signs of pulmonary embolism (such as small pulmonary infarcts or pleural effusions) or, equally importantly, an alternative diagnosis to pulmonary embolism.

Selection of the region to be surveyed from the aortic arch to 2 cm below the level of the inferior pulmonary veins (thus including all the segmental pulmonary arteries) is followed by image acquisition in a single breath hold, during continuous table feed and automated injection of contrast medium. It is most important that the patient is scanned with the thinnest slice thickness feasible. Although adequate evaluation of central pulmonary arteries has been obtained using 5 mm sections, thinner sections are generally preferable because of superior clarity. In this regard, Remy-Jardin et al (1997) documented the advantage of 2 mm sections *vs* 3 mm sections for depicting segmental (93% *vs* 85%) and subsegmental arteries (61% *vs* 37%). The same authors showed in an earlier study (1996) that 42 (10%) of 432 segmental arteries in 53 (71%) of 75 patients could not be adequately assessed

**Dr Sarah J Howling** is Consultant Radiologist in the Department of Radiology, Whittington Hospital, London and **Professor David M Hansell** is Professor of Thoracic Imaging in the Department of Radiology, Royal Brompton Hospital, London SW3 6NP

*Correspondence to: Professor DM Hansell*

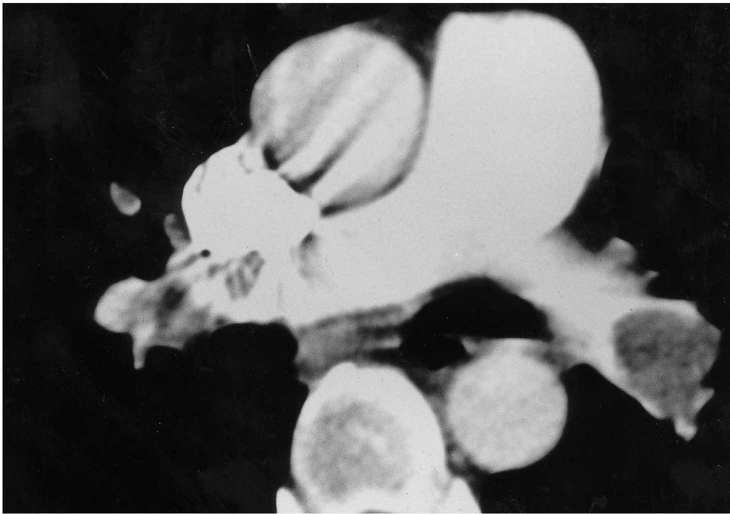

*Figure 1. Spiral computed tomography pulmonary angiogram demonstrating large, bilateral central pulmonary emboli. Streak artifact from high concentration of contrast in the superior vena cava, potentially obscures the right main pulmonary artery.*

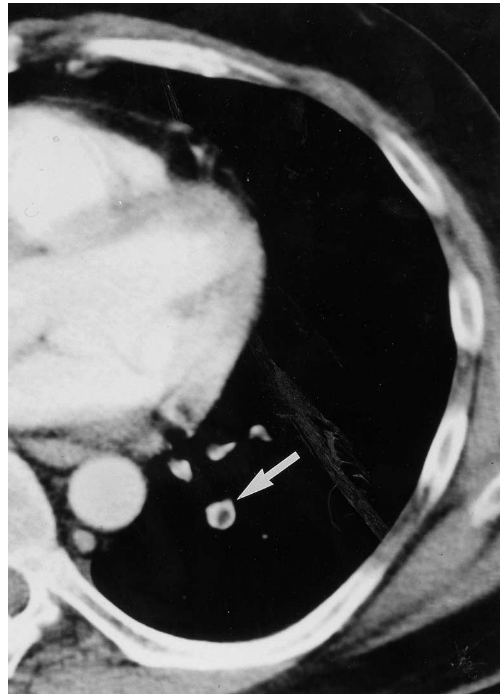

*Figure 2. A filling defect in the opacified left posterobasal segmental artery (arrow) producing a 'polo mint' appearance.*

using 5 mm sections; clearly one cannot detect an embolus in a vessel that one cannot see. Thin (2 mm) sections are now possible with the latest generation of subsecond CT scanners.

The hard copy (film) remains the basic form of image display but image analysis at a computer workstation has certain advantages. It allows the observer to modify the window settings (small emboli may be obscured if windows or levels are not selected appropriately) and permits visualization of successive axial images in a rapid display. In one study, 25% more pulmonary emboli were identified on a workstation (Gosselin et al, 1998). Multiplanar reformats may be generated on the workstation (resembling a conventional angiogram) and may be particularly useful for excluding pulmonary emboli in otherwise inconclusive studies.

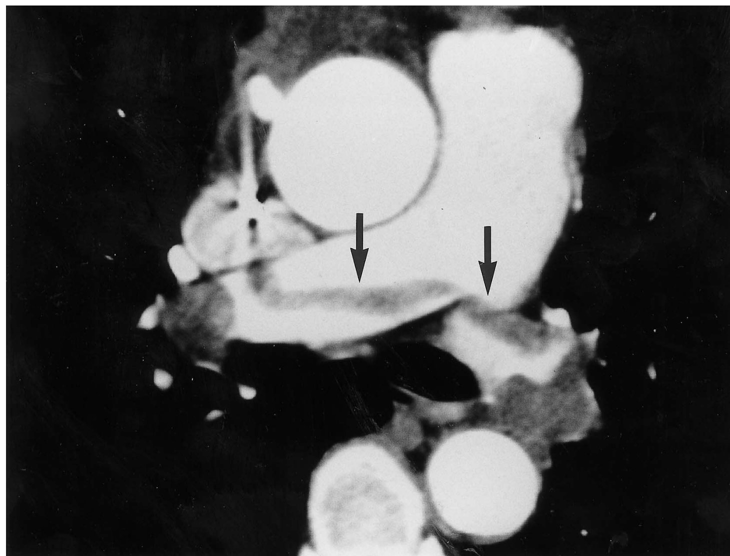

*Figure 3. Section through the right and left main pulmonary arteries shows serpiginous densities in both, an appearance characteristic of saddle emboli (arrows).*

## CT SIGNS OF PULMONARY EMBOLISM

For accurate image interpretation a thorough knowledge of pulmonary vascular anatomy and normal variations is necessary.

The most reliable and basic criterion for the diagnosis of acute pulmonary embolism is the finding of an intraluminal filling defect (*Figure 1*). Filling defects may be partial or complete. When an embolus is outlined by a rim of contrast it produces the so-called 'polo mint' appearance on axial sections (*Figure 2*). In the acute state a completely occluded vessel is typically expanded, whereas occluded vessels in chronic pulmonary embolic disease are of reduced calibre. In horizontally orientated vessels thromboemboli may be seen floating freely in the lumen, give rise to the 'railway track' sign (*Figure 3*).

With increasing age emboli become incorporated into the vessel wall (*Figure 4*). Abrupt narrowing, intraluminal webs and serpiginous vessels are other findings of chronic thromboembolic disease, and calcification within the embolus may be seen on CT in 10% of such chronic cases.

Ancillary CT findings may sometimes be of diagnostic help in patients with acute pulmonary emboli. Such changes include pleural effusions,

small areas of peripheral consolidation and atelectasis; these features are often inconspicuous or cryptic on a contemporaneous chest radiograph. Two recent studies have documented the frequency of these signs in patients with and patients without acute pulmonary embolism (Coche et al, 1998; Shah et al, 1999). The only parenchymal abnormality reliably associated with acute pulmonary emboli was peripheral wedge-shaped opacities.

Nevertheless, unexpected CT abnormalities may be of great benefit in the substantial proportion of patients examined for pulmonary embolism but who prove not to have emboli. In a recent study SCTPA provided additional information that led to an alternative diagnosis in 57 (67%) of the 85 patients without pulmonary emboli (which in this study was most commonly pneumonia) (Kim et al, 1999); this can be regarded as one of the major strengths of CT when compared with ventilation–perfusion scintigraphy or pulmonary angiography (*Figure 5*).

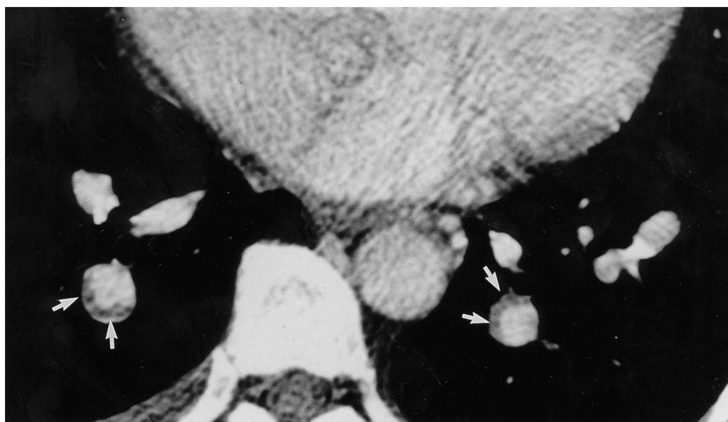

*Figure 4. Irregular mural filling defects are seen in bilateral basal segmental arteries (arrows) in a 55-year-old woman with repeated thromboembolic episodes and resulting pulmonary hypertension.*

## DIAGNOSTIC PITFALLS

Certain pitfalls in interpretation of SCTPA may lead to an incorrect diagnosis in patients with suspected pulmonary embolism. Factors may be patient-related or more commonly technical. It has been estimated that in approximately 5–10% of cases, SCTPA is suboptimal because of technical factors, most often movement artefact in tachypnoeic patients (Kuzo and Goodman, 1997). Selecting an inappropriate scan delay may produce suboptimal vascular opacification if the contrast arrives too early or too late in the pulmonary arteries under study. These problems can be avoided by obtaining additional images following a second contrast bolus or by performing an initial test bolus to check that the timing of the contrast bolus is correct.

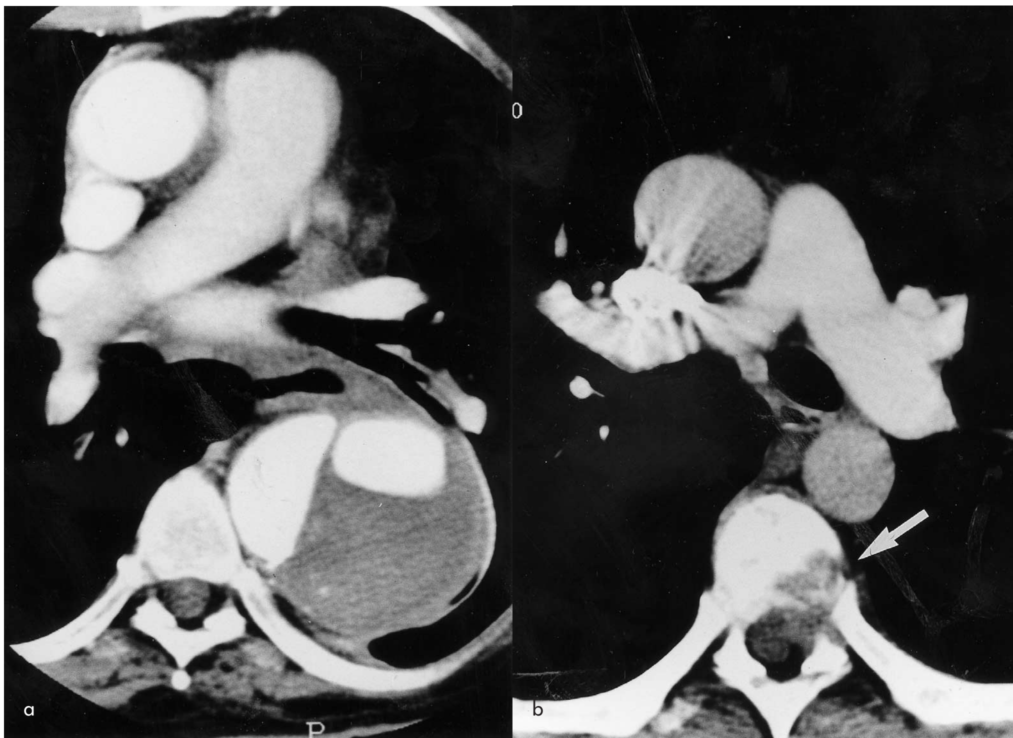


*Figure 5. Images obtained in (a) a 62-year-old man and (b) a 45-year-old woman presenting with chest pain, show no computed tomographic evidence of pulmonary emboli but provided alternate diagnoses of (a) dissection of the descending thoracic aorta and (b) a metastatic deposit in a vertebral body (arrow).*

Patient factors include problems that arise as a consequence of haemodynamic alterations within the pulmonary circulation. Most important are unilateral alterations in pulmonary vascular resistance resulting from atelectasis or pleural effusions.

Lymph nodes immediately adjacent to the pulmonary arteries may superficially mimic the appearance of pulmonary emboli and a knowledge of their typical locations is essential to minimize the number of false-positive CT interpretations (*Figure 6*).

As experience with the technique of SCTPA has grown over the last 7 years, most of these pitfalls are now readily recognized. However, vigilance is needed to ensure that only technically adequate SCTPA are acquired.

## DIAGNOSTIC ACCURACY

Since 1992, seven studies have shown that spiral CT angiography is an accurate means of diagnosing acute pulmonary embolism with sensitivities and specificities in the region of 90%, ranging from 86 to 100% and 78 to 100% respectively (Remy-Jardin et al, 1992, 1996; Senac et al, 1995; van Rossum et al, 1996, 1998; Mayo et al, 1997; Garg et al, 1998).

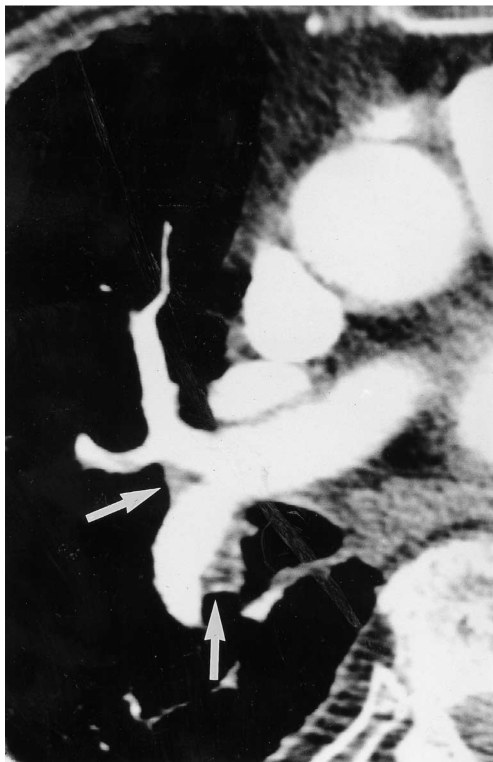

*Figure 6. Spiral computed tomography scan obtained in a 67-year-old man who presented with dyspnoea, showing right hilar lymphadenopathy (arrows). This could be confused with a pulmonary embolus. A small right pleural effusion is also present.*

This is further supported by the largest study to date, which included 401 patients with pulmonary embolism (Herold et al, 1998). The accuracy of ventilation–perfusion scans is high within either the high probability or normal categories, but as these comprise approximately 15% of cases, most patients (>60%) fit into the intermediate or low probability categories but still have a 25% chance of pulmonary embolism (PIOPED Investigators, 1990).

Additional advantages of CT over ventilation–perfusion scintigraphy are the lower percentage of non-diagnostic examinations and better interobserver agreement, which ranges from 83 to 95% for CT, compared to 70% for scintigraphy for intermediate and low probability scans (PIOPED Investigators, 1990).

All the large studies that have evaluated the accuracy of CT have been restricted to the identification of emboli within the central, lobar and segmental arteries. The prevalence of small subsegmental emboli remains debatable with varying frequencies, largely dependent on technique and the population being studied. In one report, isolated subsegmental emboli were detected at spiral CT in 5% of cases (Remy-Jardin et al, 1996), which was comparable to the figure of 5.6% in the PIOPED study (1990).

Conversely, in a study examining the distribution of emboli at pulmonary angiography, Oser et al (1996) noted a prevalence of 30% for emboli beyond the segmental level; at spiral CT, Goodman et al (1995) and van Rossum et al (1996) observed a prevalence of 36% and 20% respectively. The higher prevalence in the latter three studies may reflect inherent bias as a result of selection of a subgroup of patients with unresolved clinical and scintigraphic diagnosis of pulmonary embolism. It is probable that in a less selected patient population, less than 10% will have isolated subsegmental pulmonary emboli. The accuracy of conventional pulmonary angiography (still regarded as the gold standard examination, although rarely performed in the UK) concerning subsegmental emboli is also worth considering, since interobserver agreement has been reported to be as low as 66% for two observers and 13% for three observers (Stein et al, 1992). In other words, many subsegmental emboli may be overlooked on pulmonary angiography.

The clinical significance of isolated subsegmental emboli is hotly debated, intuitively it would seem that such emboli may be significant in those with limited cardiorespiratory reserve and pose less of a problem to the healthy individual, but there is no hard evi-

dence to support this view. How often subsegmental emboli are the harbinger of further larger emboli is also unclear.

## FUTURE TRENDS AND THE CURRENT ROLE OF SPIRAL CT

Further advances in CT technology permitting thinner sections and visualization of even smaller vessels will fuel the controversial debate on the role of spiral CT in the diagnosis of subsegmental pulmonary emboli. All the reports on the frequency of isolated subsegmental pulmonary emboli, discussed above, were before 1999 and the introduction of the latest generation of CT scanners.

Despite the arguments in favour of SCTPA as the best means of non-invasive investigation of suspected pulmonary embolism, why does ventilation–perfusion scanning remain the most commonly performed first-line investigation in the UK? A key fact is that the majority of patients in whom pulmonary embolism is suspected do not have the disease. Consequently, the indiscriminate use of CT would have dire consequences in terms of radiation dose to the population as a whole. It would also place an impossible demand on CT scanning time.

These two points emphasize the importance of a clinician's ability to stratify patients in terms of the pre-test probability of pulmonary embolism, thus patients will generally fall into two main groups. Those with a normal chest radiograph and a low pre-test probability who can be initially investigated with a ventilation–perfusion scintigram (or indeed a perfusion scintigram alone) and those patients with known cardiorespiratory disease, a high pre-test probability and an abnormal radiograph (likely to result in an indeterminate scintigram), who are best initially investigated with SCTPA. For those patients with symptoms of deep vein thrombosis and pulmonary embolism, ultrasound scanning of the lower limbs should be the first test and will be positive in approximately 50% of cases (Stein et al, 1993). HM


Coche EE, Müller NL, Kim KI, Wiggs BR, Mayo JR (1998) Acute pulmonary embolism: ancillary findings at spiral CT. *Radiology* **207:** 753–8

Garg K, Welsh CH, Feyerabend AJ et al (1998) Pulmonary embolism: diagnosis with spiral CT and ventilation-perfusion scanning-correlation with pulmonary angiographic results or clinical outcome. *Radiology* **208:** 201–8

Gosselin MV, Rubin GD, Leung AN, Rizk NW (1998) Unsuspected pulmonary embolism: prospective detection on routine helical CT scans. *Radiology* **208:** 209–15

Goodman LR, Curtin JJ, Mewissen MW et al (1995) Detection of pulmonary embolism in patients with unresolved clinical and scintigraphic diagnosis: helical CT versus angiography. *Am J Roentgenol* **164:** 1369–74

Herold C, Remy-Jardin M, Grenier PH et al (1998) Prospective evaluation of pulmonary embolism: initial results of the European Multicenter Trial (ESTIPEP). Abstract. *Radiology* **209:** 299

Kalender WA, Seissler W, Klotz E et al (1990) Spiral volumetric CT with single-breath-hold technique, continuous transport and continuous scanner rotation. *Radiology* **176:** 181–3

Kim K, Müller NL, Mayo JR (1999) Clinically suspected pulmonary embolism: utility of spiral CT. *Radiology* **210:** 693–7

Kuzo RS, Goodman LR (1997) CT evaluation of pulmonary embolism: technique and interpretation. *Am J Roentgenol* **169:** 959–65

Mayo JR, Remy-Jardin M, Müller NL et al (1997) Pulmonary embolism: prospective comparison of spiral CT and ventilation-perfusion scintigraphy. *Radiology* **205:** 447–52

Oser RF, Zuckerman DA, Gutierrez FR, Brink JA (1996) Anatomic distribution of pulmonary emboli at pulmonary angiography: implications for cross-sectional imaging. *Radiology* **199:** 31–5

PIOPED Investigators (1990) Value of ventilation/perfusion scan in acute pulmonary embolism. *JAMA* **262:** 2753–9

Remy-Jardin M, Remy J, Wattinne L, Giraud F (1992) Central pulmonary thromboembolism: diagnosis with spiral volumetric CT with the single-breath-hold technique-comparison with pulmonary angiography. *Radiology* **185:** 381–7

Remy-Jardin M, Remy J, Deschildre F et al (1996) Diagnosis of acute pulmonary embolism with spiral CT: comparison with pulmonary angiography and scintigraphy. *Radiology* **200:** 699–706

Remy-Jardin M, Remy J, Artaud D, Deschildre F, Duhamel A (1997) Peripheral pulmonary arteries: optimization of the spiral CT acquisition protocol. *Radiology* **204:** 157–63

Senac JP, Verhnet H, Bousquet C et al (1995) Embolie pulmonaire: apport de la tomodensitométrie hélicoïdale. *J Radiol* **76:** 339–45

Shah AA, Davis SD, Gamsu G, Intriere L (1999) Parenchymal and pleural findings in patients with and patients without acute pulmonary embolism detected at spiral CT. *Radiology* **211:** 147–53

Stein PD, Athanasoulis C, Alavi A et al (1992) Complications and validity of pulmonary angiography in acute pulmonary embolism. *Circulation* **85:** 462–8

Stein PD, Hull RD, Saltzman HA, Pineo G (1993) Strategy for diagnosis of patients with suspected acute pulmonary embolism. *Chest* **103:** 1553–9

van Rossum AB, Pattynama PM, Ton E et al (1996) Pulmonary embolism: validation of spiral CT angiography in 149 patients. *Radiology* **201:** 467–70

van Rossum AB, Pattynama PM, Mallens WM, HermansJ, Heijerman HG (1998) Can helical CT replace scintigraphy in the diagnostic process in suspected pulmonary embolism? A retrolective-prolective cohort study focussing on total diagnostic yield. *Eur Radiol* **8:** 90–6


## KEY POINTS

- Conventional computed tomography (CT) acquires too slowly to allow the consistent opacification of the pulmonary arteries which is needed for the detection of emboli.
- Current contrast-enhanced spiral CT reliably shows pulmonary emboli in the segmental, lobar and main pulmonary arteries (overall sensitivity and specificity greater than 90%).
- Unenhanced CT scans should be acquired before spiral CT pulmonary angiography to show secondary signs of pulmonary embolism or an alternate diagnosis.
- Further advances in spiral CT technology, notably reduced section thickness, will allow detection of emboli within subsegmental pulmonary arteries.
- Spiral CT should not be regarded as the first-line test for all patients with suspected pulmonary embolism, particularly for patients with a low pretest probability and normal chest radiograph.