Sensitivity and Specificity of Helical Computed Tomography in the Diagnosis of Pulmonary Embolism: A Systematic Review

Suman W. Rathbun, MD; Gary E. Raskob, PhD; and Thomas L. Whitsett, MD

Purpose: To determine the sensitivity and specificity of helical computed tomography (CT) for the diagnosis of pulmonary embolism and to determine the safety of withholding anticoagulant therapy in patients who have clinically suspected pulmonary embolism and negative results on helical CT.

Data Sources: The MEDLINE database was searched for all reports published from 1986 to October 1999 that evaluated the use of helical CT for the diagnosis of pulmonary embolism. Bibliographies of the retrieved articles were cross-checked to identify additional studies.

Study Selection: All prospective English-language studies were selected. Retrospective studies, review articles, and case reports were excluded, and 5 of the 20 identified articles were excluded. The scientific validity of the remaining 15 articles was assessed.

Data Extraction: Two of the authors used a priori, predefined criteria to independently assess each study. A third author resolved disagreements by adjudication. The predefined criteria were inclusion of a consecutive series of all patients with suspected pulmonary embolism, inclusion of patients with and those without pulmonary embolism, a broad spectrum of patient characteristics, performance of helical CT and pulmonary angiography (or an appropriate reference test) in all patients, and independent interpretation of the CT scan and pulmonary angiogram (or reference test). Specific data on sensitivity and specificity and the associated 95% CIs were recorded when available.

Data Synthesis: No study met all of the predefined criteria for adequately evaluating sensitivity and specificity. The reported sensitivity of helical CT ranged from 53% to 100%, and specificity ranged from 81% to 100%. In no prospective study was anticoagulant therapy withheld without further testing for venous thromboembolism in consecutive patients with suspected pulmonary embolism. One prospective study reported the outcome of selected patients with negative results on helical CT who did not receive anticoagulant therapy.

Conclusions: Use of helical CT in the diagnosis of pulmonary embolism has not been adequately evaluated. The safety of withholding anticoagulant treatment in patients with negative results on helical CT is uncertain. Definitive large, prospective studies should be done to evaluate the sensitivity, specificity, and safety of helical CT for diagnosis of suspected pulmonary embolism.

Ann Intern Med. 2000;132:227-232.

For author affiliations and current addresses, see end of text.

Pulmonary embolism is a major health problem in the United States. The estimated annual incidence is 69 cases per 100 000 persons (1), which means that more than 175 000 persons develop established pulmonary embolism each year. Prospective studies have documented a 30% to 40% prevalence of pulmonary embolism in patients who have clinical features of suspected pulmonary embolism (2–4). Therefore, clinically suspected pulmonary embolism is present in more than 575 000 persons in the United States each year.

It is difficult to diagnose pulmonary embolism because the clinical diagnosis is nonspecific (2–8) and all of the objective tests have clinical or practical limitations (2–6). The ventilation–perfusion lung scan has been the first-line test for more than 20 years. However, 60% to 70% of lung scans are nondiagnostic (2–4), and combining clinical assessment with lung scan results or using a clinical algorithm fails to identify 20% of patients with pulmonary embolism (3, 4, 8). Pulmonary angiography is the gold standard (9–12), but it is invasive and expensive, may be impractical or unavailable in some clinical settings, and causes cardiac or pulmonary complications in 3% to 4% of patients (12, 13). Objective testing for deep venous thrombosis is useful if the results are positive (4–6, 14), but negative results do not exclude pulmonary embolism (4–6, 11, 14, 15). Serial testing for proximal deep venous thrombosis can be used as an alternative to pulmonary angiography in selected patients, such as those with adequate cardiorespiratory reserve or a low or moderate suspicion of pulmonary embolism (14, 16, 17). The D-dimer assay is promising as an exclusion test, but a positive result is nonspecific and occurs in 40% to 69% of patients (18, 19). Therefore, definitive testing for the presence or absence of pulmonary embolism is required for many patients, such as those with severe underlying cardiopulmonary disease and inadequate cardiorespiratory reserve (5, 6, 17, 20).

Recently, interest has developed in using helical computed tomography (CT), also known as spiral

See editorial comment on pp 240-242.

Table 1. Criteria Used To Appraise Prospective Studies Identified by Literature Search*

Criteria used to assess studies that evaluated the sensitivity and specificity of helical CT
Does the study include a consecutive series of all patients with suspected pulmonary embolism?
Do all patients undergo both CT and the gold standard, pulmonary angiography? (Normal results on ventilation–perfusion lung scanning were accepted as an alternate reference standard for the absence of pulmonary embolism.)
Is the angiogram read without knowledge of the CT scan and vice versa?
Does the study examine a broad spectrum of patients (including patients with and those without pulmonary embolism) and a broad spectrum of patient characteristics (such as age; sex; high, intermediate, or low clinical suspicion of pulmonary embolism; comorbid conditions that may confuse the diagnosis; and size of pulmonary embolism on angiography)?
What generations of vessels are imaged by CT (lobar, segmental, subsegmental)?
What is the size of pulmonary embolism on pulmonary angiography (lobar, segmental, subsegmental)?
What is the reported sensitivity and specificity of CT?
What are the 95% CIs for sensitivity and specificity?
Criteria used to assess studies that evaluated the safety of withholding anticoagulant therapy on the basis of negative CT results
Did all patients with negative results on CT have anticoagulant therapy withdrawn or withheld?
What is the follow-up period (none, ≤3 mo, 3–6 mo, >6 mo)?
What were the outcomes on follow-up (fatal pulmonary embolism, symptomatic pulmonary embolism, symptomatic deep venous thrombosis)?

* CT = computed tomography.

CT, for the diagnosis of pulmonary embolism (21–23). Helical CT scanning produces a volumetric two-dimensional image of the lung by rotating the detector around the patient. Total acquisition time is less than 30 seconds. Pulmonary embolism appears as a filling defect that may be central, eccentric, or mural and may partially or totally occlude the vessel.

Helical CT is minimally invasive and can help identify other disorders that may be responsible for the patient's symptoms. However, it is expensive to perform and interpret; it requires that a contrast agent be intravenously injected; and it is often difficult or impossible to perform in patients who require ventilation, are hemodynamically unstable, or cannot cooperate. Some researchers have recommended helical CT as a first-line replacement for lung scans and pulmonary angiography (23–25), and others have suggested that diagnostic algorithms based on helical CT be used in selected patients (24, 26, 27). Several experts have called for more research (24–26, 28).

Because of the debate about the role of helical CT in the diagnosis of pulmonary embolism (29), we performed a systematic review of the literature (30). Our review had two objectives: to determine the sensitivity and specificity of helical CT for the diagnosis of pulmonary embolism in symptomatic patients, and to determine the safety of withholding anticoagulant therapy without further objective testing for venous thromboembolism in patients who have clinically suspected pulmonary embolism and negative results on helical CT.

Methods

Literature Search and Data Sources

We searched the MEDLINE database for literature published from 1986 through November 1999. The MeSH terms *pulmonary embolism* and *tomography, x-ray computed* were used in separate searches, and studies found during each search were combined. Limits were set for human only and English language only. We supplemented this reference list by cross-checking bibliographies of retrieved articles to identify additional studies.

Study Selection and Data Extraction

Before performing the literature review, we defined criteria for inclusion of studies and for assessing the validity of these studies (31). We decided a priori to include all prospective studies identified by the literature search, including abstracts. Retrospective studies, review articles, and case reports were excluded.

Two of the authors reviewed each article or abstract independently using the criteria outlined in **Table 1**. These criteria were established a priori before the articles were reviewed, according to established methodologic standards for evaluation of diagnostic tests (32, 33). Different criteria were used to assess studies that evaluated the sensitivity and specificity of helical CT for diagnosis of pulmonary embolism and studies that evaluated the safety of withholding anticoagulant therapy in patients with negative results on helical CT. A third independent reviewer resolved disagreements by adjudication.

Data Synthesis

Literature Search and Data Sources

The literature search identified 20 articles (34–53) and 6 abstracts (54–59). Five articles were excluded; 4 were retrospective studies (49–52), and 1 was a series of case reports (53). The abstracts were excluded from further analysis because they reported the results of subsequent articles or contained insufficient information for evaluation of study validity. Fifteen original prospective studies (34–48) were assessed by using the criteria in **Table 1**. Of these 15 studies, 13 were unique. Two studies by van Rossum and colleagues (38, 40) included some of the same patients (van Rossum AB. Personal communication). These studies evaluated 249 and 149 patients, respectively (38, 40) (**Table 2**).

Study Appraisal

Table 2 summarizes the results of our assessment

Table 2. Prospective Studies Evaluating the Use of Helical Computed Tomography in the Diagnosis of Suspected Pulmonary Embolism*

Study (Reference)	Year	Patients	Patients Who Had Angiography	Included Consecutive Patients	Blind Interpretation†	Included a Broad Spectrum of Patients	Vessels Imaged	Vessels in Which Size of Pulmonary Embolism Was Determined by Angiography	Sensitivity	Specificity	Follow-up
		n							% (n/n)		
Remy-Jardin et al. (34)	1992	42	42	–	Yes	Yes	Lobar, segmental, subsegmental	Lobar, segmental	100 (36/36)	95 (18/19)	None
Blum et al. (35)‡	1994	10	10	No	Yes	No	Lobar, segmental, subsegmental	–	100 (7/7)	100 (3/3)	None
Dresel et al. (36)	1995	25	0	Yes	Yes	–	Lobar, segmental	NA	NA	NA	None
Goodman et al. (37)	1995	20	20	No	Yes	–	Lobar, segmental, subsegmental	Lobar, segmental, subsegmental	64 (7/11)	89 (8/9)	None
van Rossum et al. (38)§	1996	249	45	Yes	No	–	Lobar, segmental, subsegmental	–	90 (37/41)	97 (36/37)	None
Remy-Jardin et al. (39)	1996	75	75	–	Yes	–	Lobar, segmental	–	91 (39/43)	100 (25/25)	None
van Rossum et al. (40)§‖	1996	149	56	–	–	–	–	Lobar, segmental, subsegmental	94 (64/68) 82 (56/68)	96 (78/81) 93 (75/81)	None
Sostman et al. (41)§‖	1996	53	21	–	Yes	–	Lobar, segmental, subsegmental	Lobar, segmental, subsegmental	77 69 62 77 92	93 100 100 80 73	None
Russi et al. (42)¶	1997	20	1	No	–	No	–	–	NA	NA	None
Mayo et al. (43)**	1997	142	41	–	Yes	–	Lobar, segmental	–	87 (40/46)	95 (88/93)	Selected, 3 mo
Ferretti et al. (44)††	1997	164	15	No	–	No	Lobar, segmental	Lobar, segmental	NA	NA	3 mo
Cross et al. (45)	1998	39	2	–	No	–	Lobar, segmental, subsegmental	NA	NA	NA	Retrospective record review
Garg et al. (46)	1998	185	26	No	Yes	–	Lobar, segmental, subsegmental	–	67 (4/6)	100 (18/18)	Selected, 5–42 wk
Drucker et al. (47)‖	1998	47	47	No	–	–	Lobar, segmental, subsegmental	Lobar, segmental	60 (9/15) 53 (8/15)	81 (26/32) 97 (31/32)	None
Kim et al. (48)**	1999	110	7	No	No	–	Lobar, segmental	–	92 (23/25)	88 (75/85)	Record review, 3–27 mo

* NA = not applicable.
† Computed tomography (CT) and the reference test were assessed independently.
‡ Included only patients with suspected "massive" pulmonary embolism.
§ Combined reference standards were used for the presence of pulmonary embolism (positive results on angiography or high-probability ventilation–perfusion scan) or the absence of pulmonary embolism (normal results on ventilation–perfusion scan or negative results on angiography).
‖ Included multiple readers.
¶ Included only patients with positive results on CT.
** Included CT results as part of the reference standard for the presence or absence of pulmonary embolism.
†† Included only patients who had negative results on duplex ultrasonography of the legs and intermediate-probability ventilation–perfusion lung scans.

of the 15 prospective studies. Only 2 studies (36, 38) explicitly stated that a consecutive series of all patients with suspected pulmonary embolism was evaluated. In 8 studies, helical CT and pulmonary angiography were interpreted independently (34–37, 39, 41, 43, 46). Only 1 study (34) included enough data to allow us to conclude that a broad spectrum of patients had been evaluated. Thirteen articles included a description of the size of the vessels imaged by helical CT (34–39, 41, 43–48). Six studies described the size of the pulmonary embolism on angiography (34, 37, 40, 41, 44, 47).

Sensitivity and Specificity

The reported sensitivity of helical CT ranged from 53% to 100%, and the reported specificity ranged from 81% to 100% (**Table 2**). Only four articles reported 95% CIs (40, 41, 44, 46).

Safety of Withholding Anticoagulant Therapy

No prospective study was identified in which anticoagulant therapy was withheld without additional testing for venous thromboembolism in consecutive patients who had suspected pulmonary embolism and negative results on helical CT. One study prospectively followed up selected patients who had suspected pulmonary embolism and negative results on helical CT (44). Patients were eligible if they had an intermediate-probability ventilation–perfusion lung scan and negative results on duplex ultrasonography of the legs. Computed tomography yielded positive results in 39 of 164 patients and negative

results in 125 of 164 patients. Pulmonary angiography was performed in 15 of these 125 patients and showed pulmonary embolism in 1 patient. All 15 patients were treated with anticoagulant therapy. A total of 109 patients with negative results on helical CT did not receive anticoagulant therapy and were followed for 3 months. Fatal pulmonary embolism was strongly suspected in 1 patient who died 10 days after study entry. In addition, high-probability ventilation–perfusion lung scans documented symptomatic pulmonary embolism in 2 patients at 2 months and 3 months of follow-up (44).

Discussion

We sought to determine the sensitivity and specificity of helical CT for the diagnosis of pulmonary embolism and the safety of withholding anticoagulant therapy in patients with negative results on helical CT. Our results support four major inferences.

First, none of the studies met all of the methodologic criteria for adequately evaluating the sensitivity and specificity of a diagnostic test (32, 33). Several studies were missing key data on the methods used to select patients, whether helical CT and the reference test were interpreted independently, and whether the study sample included a broad spectrum of patients with suspected pulmonary embolism. Details were often missing on the clinical features of patients at presentation, the size of pulmonary embolism on angiography, and the presence or absence of comorbid conditions that may have confused the diagnosis. All studies to date have included relatively few patients who underwent both helical CT and an appropriate reference test.

Second, a wide range of sensitivity (53% to 100%) was reported for helical CT (**Table 2**). Two recent studies reported sensitivities of 60% and 67% (46, 47), and in one of these studies (47) all cases of pulmonary embolism documented by pulmonary angiography involved segmental or lobar arteries. The wide range of sensitivity among these studies may be due to differences in patient selection, extent of pulmonary embolism, technology and testing methods (including pitch, collimator thickness, and the concentration of the contrast agent), methods of interpretation (workstations or hard copy, windowing of images), reader experience, and interobserver variation.

Third, our results suggest that interobserver variation is a potentially important limitation of helical CT. Three studies reported interobserver variation in the sensitivity and specificity of helical CT (40, 41, 47). In two of these studies (40, 41), sensitivity differed substantially among observers. Sostman and colleagues (41) reported a range of 62% to 92% among 5 observers. In a study by van Rossum and coworkers (40), one observer reported a sensitivity of 82% and another reported a sensitivity of 94%. In addition, two studies (41, 47) found clinically important differences in specificity among observers. Sostman and colleagues (41) reported a range of 73% to 100% among 5 observers. Drucker and coworkers (47) found that one observer reported a specificity of 81% and another reported a specificity of 97%. Observer variation and error in the interpretation of radiologic tests is a general problem (60, 61) that also occurs with other imaging tests for venous thromboembolism (3, 62, 63).

Fourth, no study has adequately evaluated the safety of withholding anticoagulant therapy without additional testing for venous thromboembolism in patients who have negative results on helical CT. Because of this, and because several studies have reported a low sensitivity for helical CT (37, 41, 46, 47), it may not be safe to withhold anticoagulant therapy on the basis of negative CT test results. Four studies—one prospective study (44) and three retrospective reviews of medical records (45, 51, 52)—have attempted to evaluate the safety of withholding anticoagulant treatment in patients with negative results on helical CT. In each of these studies, anticoagulant treatment was withheld only in selected patients, and some patients underwent pulmonary angiography or received anticoagulant treatment for other reasons (for example, high clinical suspicion) regardless of negative test results. These studies do not allow us to make definitive conclusions about the safety of withholding treatment on negative CT results because co-intervention with angiography or anticoagulant treatment may have prevented subsequent thromboembolic events.

We conclude that use of helical CT for the diagnosis of pulmonary embolism has not been adequately evaluated. The safety of withholding anticoagulant treatment in a patient with suspected pulmonary embolism and negative results on helical CT is uncertain. On the basis of the current best evidence, clinicians should not use negative results on helical CT as the diagnostic end point for excluding pulmonary embolism. The data indicate that helical CT may fail to detect pulmonary embolism that is shown on angiography to involve segmental or lobar vessels. This result does not support the idea that only clinically unimportant cases of pulmonary embolism go undetected on helical CT. A positive result on helical CT may be useful for establishing the presence of pulmonary embolism and for indicating antithrombotic treatment. However, further testing for venous thromboembolism may be indicated in a patient who has positive results on helical CT and is at high risk for bleeding.

Helical CT has an uncertain role in the diagnosis of suspected pulmonary embolism. The best available evidence does not support the use of helical CT as a first-line test because of the uncertain validity of a negative result and the lack of data from definitive prospective studies on which to base a rigorous cost-effectiveness analysis. In patients with nondiagnostic lung scans, helical CT and angiography are often unnecessary when assessment of cardiorespiratory reserve or use of a clinical model is combined with serial noninvasive testing for deep venous thrombosis (14, 16, 17). Furthermore, studies have shown that the plasma D-dimer assay is a promising test for excluding pulmonary embolism (18, 19) and is much less expensive than helical CT. If these initial results (18, 19) are confirmed in larger prospective studies of patient management, D-dimer assays combined with a clinical model or compression ultrasonography of the legs will markedly limit the need for helical CT or angiography.

At present, helical CT may be useful for establishing a diagnosis of pulmonary embolism in selected patients who have nondiagnostic lung scans, negative results on objective tests for deep venous thrombosis of the legs, and inadequate cardiorespiratory reserve (20) or a high probability of pulmonary embolism according to a clinical model (17). However, the cost-effectiveness of performing helical CT rather than proceeding directly to pulmonary angiography in such patients remains uncertain. There is an urgent need for prospective studies that use the design features outlined in **Table 1** to definitively evaluate the sensitivity, specificity, and cost-effectiveness of helical CT in the diagnosis of suspected pulmonary embolism.

From University of Oklahoma Health Sciences Center, Oklahoma City, Oklahoma.

Grant Support: By a College of Medicine Alumni Research Award (Dr. Rathbun). Dr. Raskob is a Samuel Roberts Noble Foundation Presidential Professor.

Requests for Single Reprints: Suman W. Rathbun, MD, Department of Medicine, WP 3120, University of Oklahoma Health Sciences Center, PO Box 26901, Oklahoma City, OK 73190.

Requests To Purchase Bulk Reprints (minimum, 100 copies): Barbara Hudson, Reprints Coordinator; phone, 215-351-2657; e-mail, bhudson@mail.acponline.org.

Current Author Addresses: Dr. Rathbun: Department of Medicine, WP 3120, University of Oklahoma Health Sciences Center, Box 26901, Oklahoma City, OK 73190.
Dr. Raskob: Department of Biostatistics and Epidemiology, University of Oklahoma Health Sciences Center, Box 26901, Oklahoma City, OK 73190.
Dr. Whitsett: Department of Medicine, University of Oklahoma Health Sciences Center, Box 26901, Oklahoma City, OK 73190.

References

1. **Silverstein MD, Heit JA, Mohr DN, Petterson TM, O'Fallon WM, Melton LJ.** Trends in the incidence of deep vein thrombosis and pulmonary embolism: a 25-year population-based study. Arch Intern Med. 1998;158: 585-93.
2. **Miniati M, Pistolesi M, Marini C, di Ricco G, Formichi B, Prediletto R, et al.** Value of perfusion lung scan in the diagnosis of pulmonary embolism: results of the Prospective Investigative Study of Acute Pulmonary Embolism diagnosis (PISA-PED). Am J Respir Crit Care Med. 1996;154:1387-93.
3. Value of the ventilation/perfusion scan in acute pulmonary embolism. Results of the prospective investigation of pulmonary embolism diagnosis (PIOPED). The PIOPED Investigators. JAMA. 1990;263:2753-9.
4. **Hull RD, Hirsh J, Carter CJ, Raskob GE, Gill GJ, Jay RM, et al.** Diagnostic value of ventilation-perfusion lung scanning in patients with suspected pulmonary embolism. Chest. 1985;88:819-28.
5. **Hyers TM.** Venous thromboembolism. Am J Respir Crit Care Med. 1999;159: 1-14.
6. **Goldhaber SZ.** Pulmonary embolism. N Engl J Med. 1998;339:93-104.
7. **Stein PD, Saltzman HA, Weg JG.** Clinical characteristics of patients with acute pulmonary embolism. Am J Cardiol. 1991;68:1723-4.
8. **Miniati M, Prediletto R, Formichi B, Marini C, Di Ricco G, Tonelli L, et al.** Accuracy of clinical assessment in the diagnosis of pulmonary embolism. Am J Respir Crit Care Med. 1999;159:864-71.
9. **Dalen JE, Brooks HL, Johnson LW, Meister SG, Szucs MM, Dexter L.** Pulmonary angiography in acute pulmonary embolism: indications, techniques, and results in 367 patients. Am Heart J. 1971;81:175-85.
10. **Novelline RA, Baltarowich OH, Athanasoulis CA, Waltman AC, Greenfield AJ, McKusick KA.** The clinical course of patients with suspected pulmonary embolism and a negative pulmonary arteriogram. Radiology. 1978; 126:561-7.
11. **Hull RD, Hirsh J, Carter CJ, Jay RM, Dodd PE, Ockelford PA, et al.** Pulmonary angiography, ventilation lung scanning, and venography for clinically suspected pulmonary embolism with abnormal perfusion lung scan. Ann Intern Med. 1983;98:891-9.
12. **Stein PD, Athanasoulis C, Alavi A, Greenspan RH, Hales CA, Saltzman HA, et al.** Complications and validity of pulmonary angiography in acute pulmonary embolism. Circulation. 1992;85:462-8.
13. **Mills SR, Jackson DC, Older RA, Heaston DK, Moore AV.** The incidence, etiologies, and avoidance of complications of pulmonary angiography in a large series. Radiology. 1980;136:295-9.
14. **Kearon C, Ginsberg JS, Hirsh J.** The role of venous ultrasonography in the diagnosis of suspected deep venous thrombosis and pulmonary embolism. Ann Intern Med. 1998;129:1044-9.
15. **Turkstra F, Kuijer PM, van Beek EJ, Brandjes DP, ten Cate JW, Büller HR.** Diagnostic utility of ultrasonography of leg veins in patients suspected of having pulmonary embolism. Ann Intern Med. 1997;126:775-81.
16. **Hull RD, Raskob GE, Ginsberg JS, Panju AA, Brill-Edwards P, Coates G, et al.** A noninvasive strategy for the treatment of patients with suspected pulmonary embolism. Arch Intern Med. 1994;154:289-97.
17. **Wells PS, Ginsberg JS, Anderson DR, Kearon C, Gent M, Turpie AG, et al.** Use of a clinical model for safe management of patients with suspected pulmonary embolism. Ann Intern Med. 1998;129:997-1005.
18. **Ginsberg JS, Wells PS, Kearon C, Anderson D, Crowther M, Weitz JI, et al.** Sensitivity and specificity of a rapid whole-blood assay for D-dimer in the diagnosis of pulmonary embolism. Ann Intern Med. 1998;129:1006-11.
19. **Perrier A, Desmarais S, Miron MJ, de Moerloose P, Lepage R, Slosman D, et al.** Non-invasive diagnosis of venous thromboembolism in outpatients. Lancet. 1999;353:190-5.
20. **Hull RD, Raskob GE, Pineo GF, Brant RF.** The low-probability lung scan. A need for change in nomenclature. Arch Intern Med. 1995;155:1845-51.
21. **Remy-Jardin M, Remy J, Artaud D, Fribourg M, Beregi JP.** Spiral CT of pulmonary embolism: diagnostic approach, interpretive pitfalls and current indications. Eur Radiol. 1998;8:1376-90.
22. **Layish DT, Tapson VF.** New imaging techniques for the diagnosis of pulmonary embolism. Curr Opin Pulm Med. 1997;3:280-5.
23. **Goodman LR, Lipchick RJ.** Diagnosis of acute pulmonary embolism: time for a new approach. Radiology. 1996;199:25-7.
24. **Remy-Jardin M, Remy J, Artaud D, Deschildre F, Beregi JP.** Opinion response to acute pulmonary embolism: the role of computed tomographic imaging. J Thorac Imaging. 1997;12:92-5.
25. **Mayo JR.** Opinion response to acute pulmonary embolism: the role of computed tomographic imaging. J Thorac Imaging. 1997;12:95-7.
26. **Stein P.** Opinion response to acute pulmonary embolism: the role of computed tomographic imaging. J Thorac Imaging. 1997;12:86-9.
27. **Sostman HD.** Opinion response to acute pulmonary embolism: the role of computed tomographic imaging. J Thorac Imaging. 1997;12:89-92.
28. **Gefter WB, Palevsky HI.** Opinion response to acute pulmonary embolism: the role of computed tomographic imaging. J Thorac Imaging. 1997;12:97-100.
29. **Rubin GD.** Helical CT for the detection of acute pulmonary embolism: experts debate. J Thorac Imaging. 1997;12:81-102.
30. **Cook DJ, Mulrow CD, Haynes RB.** Systematic reviews: synthesis of best evidence for clinical decisions. Ann Intern Med. 1997;126:376-80.
31. **Meade MO, Richardson WS.** Selecting and appraising studies for a systematic review. Ann Intern Med. 1997;127:531-7.
32. **Jaeschke R, Guyatt G, Sackett DL.** Users' guides to the medical literature. III. How to use an article about a diagnostic test. A. Are the results of the study valid? Evidence-Based Medicine Working Group. JAMA. 1994;271:389-91.
33. **Jaeschke R, Guyatt GH, Sackett DL.** Users' guides to the medical literature.

III. How to use an article about a diagnostic test. B. What are the results and will they help me in caring for my patients? The Evidence-Based Medicine Working Group. JAMA. 1994;271:703-7.
34. **Remy-Jardin M, Remy J, Wattinne L, Giraud F.** Central pulmonary thromboembolism: diagnosis with spiral volumetric CT with the single-breath-hold technique—comparison with pulmonary angiography. Radiology. 1992;185: 381-7.
35. **Blum AG, Delfau F, Grignon B, Beurrier D, Chabot F, Claudon M, et al.** Spiral-computed tomography versus pulmonary angiography in the diagnosis of acute massive pulmonary embolism. Am J Cardiol. 1994;74:96-8.
36. **Dresel S, Stäbler A, Scheidler J, Holzknecht N, Tatsch K, Hahn K.** Diagnostic approach in acute pulmonary embolism: perfusion scintigraphy versus spiral computed tomography. Nucl Med Commun. 1995;16:1009-15.
37. **Goodman LR, Curtin JJ, Mewissen MW, Foley WD, Lipchik RJ, Crain MR, et al.** Detection of pulmonary embolism in patients with unresolved clinical and scintigraphic diagnosis: helical CT versus angiography. AJR Am J Roentgenol. 1995;164:1369-74.
38. **van Rossum AB, Treurniet FE, Kieft GJ, Smith SJ, Schepers-Bok R.** Role of spiral volumetric computed tomographic scanning in the assessment of patients with clinical suspicion of pulmonary embolism and an abnormal ventilation/perfusion lung scan. Thorax. 1996;51:23-8.
39. **Remy-Jardin M, Remy J, Deschildre F, Artaud D, Beregi JP, Hossein-Foucher C, et al.** Diagnosis of pulmonary embolism with spiral CT: comparison with pulmonary angiography and scintigraphy. Radiology. 1996;200: 699-706.
40. **van Rossum AB, Pattynama PM, Ton ER, Treurniet FE, Arndt JW, van Eck B, et al.** Pulmonary embolism: validation of spiral CT angiography in 149 patients. Radiology. 1996;201:467-70.
41. **Sostman HD, Layish DT, Tapson VF, Spritzer CE, DeLong DM, Trotter P, et al.** Prospective comparison of helical CT and MR imaging in clinically suspected acute pulmonary embolism. J Magn Reson Imaging. 1996;6:275-81.
42. **Russi TJ, Libby DM, Henschke CI.** Clinical utility of computer tomography in the diagnosis of pulmonary embolism. Clin Imaging. 1997;21:175-82.
43. **Mayo JR, Remy-Jardin M, Müller NL, Remy J, Worsley DF, Hossein-Foucher C, et al.** Pulmonary embolism: prospective comparison of spiral CT with ventilation-perfusion scintigraphy. Radiology. 1997;205:447-52.
44. **Ferretti GR, Bosson JL, Buffaz PD, Ayanian D, Pison C, Blanc F, et al.** Acute pulmonary embolism: role of helical CT in 164 patients with intermediate probability at ventilation-perfusion scintigraphy and normal results at duplex US of the legs. Radiology. 1997;205:453-8.
45. **Cross JJ, Kemp PM, Walsh CG, Flower CD, Dixon AK.** A randomized trial of spiral CT and ventilation perfusion scintigraphy for the diagnosis of pulmonary embolism. Clin Radiol. 1998;53:177-82.
46. **Garg K, Welsh CH, Feyerabend AJ, Subber SW, Russ PD, Johnston RJ, et al.** Pulmonary embolism: diagnosis with spiral CT and ventilation-perfusion scanning—correlation with pulmonary angiographic results or clinical outcome. Radiology. 1998;208:201-8.
47. **Drucker EA, Rivitz SM, Shepard JA, Boiselle PM, Trotman-Dickenson B, Welch TJ, et al.** Acute pulmonary embolism: assessment of helical CT for diagnosis. Radiology. 1998;209:235-41
48. **Kim KI, Muller NL, Mayo JR.** Clinically suspected pulmonary embolism: utility of spiral CT. Radiology. 1999;210:693-7.
49. **Coche EE, Muller NL, Kim KI, Wiggs BR, Mayo JR.** Acute pulmonary embolism: ancillary findings at spiral CT. Radiology. 1998;207:753-8.
50. **Van Rossum AB, Pattynama PM, Mallens WM, Hermans J, Heijerman HG.** Can helical CT replace scintigraphy in the diagnostic process in suspected pulmonary embolism? A retrolective-prolective cohort study focusing on total diagnostic yield. Eur Radiol. 1998;8:90-6.
51. **Garg K, Sieler H, Welsh CH, Johnston RJ, Russ PD.** Clinical validity of helical CT being interpreted as negative for pulmonary embolism: implications for patient treatment. AJR Am J Roentgenol. 1999;172:1627-31.
52. **Lomis NN, Yoon HC, Moran AG, Miller FJ.** Clinical outcomes of patients after a negative spiral CT pulmonary arteriogram in the evaluation of acute pulmonary embolism. J Vasc Interv Radiol. 1999;10:707-12.
53. **Loud PA, Grossman ZD, Klippenstein DL, Ray CE.** Combined CT venography and pulmonary angiography: a new diagnostic technique for suspected thromboembolic disease. Am J Roentgenol. 1998;170:951-4.
54. **Goodman LR, Curtin JJ, Foley WD, Liphick RJ, Mewisson MW, Sagar KB, et al.** Helical CT of patients with "unresolved suspicion" of pulmonary embolism: prospective study [Abstract]. Radiology. 1994;193(Suppl):262.
55. **Rossum AV, Kieft G, Treuniet F, Schepers-Bok F, Smith S.** Spiral volumetric CT in patients with clinical suspicion of pulmonary embolism [Abstract]. Radiology. 1994;193(Suppl):262.
56. **Remy-Jardin MJ, Remy J, Petyt L, Duhamel A, Marchandise X.** Diagnosis of acute pulmonary embolism with spiral CT: comparison with pulmonary angiography and scintigraphy [Abstract]. Radiology. 1995;197(Suppl):303.
57. **van Rossum AB, Pattynama PM, Treurniet FE, Schpers R, Kieft GJ.** Spiral CT angiography for detection of pulmonary embolism: validation in 126 patients [Abstract]. Radiology. 1995;197(Suppl):303.
58. **Sostman HD, Layish DT, Spritzer CE, Goodman PC, Patz EF Jr, MacFall JR, et al.** MR imaging and CT for detecting pulmonary embolism and venous thromboembolism [Abstract]. Radiology. 1995;197(Suppl):303.
59. **Herold CJ, Remy-Jardin MJ, Grenier PA, Remy J, Verschakelen JA, Prokop M.** Prospective evaluation of pulmonary embolism: initial results of the European Multicenter Trial (ESTIPEP) [Abstract]. Radiology. 1998;209(Suppl): 299.
60. **Robinson PJ.** Radiology's Achilles' heel: error and variation in the interpretation of the Rontgen image. Br J Radiol. 1997;70:1085-98.
61. **Siegle RL, Baram EM, Reuter SR, Clarke EA, Lancaster JL, McMahan CA.** Rates of disagreement in imaging interpretation in a group of community hospitals. Acad Radiol. 1998;5:148-54.
62. **Lensing AW, van Beek EJ, Demers C, Tiel-van Buul MM, Yakemchuk V, van Dongen A, et al.** Ventilation-perfusion lung scanning and the diagnosis of pulmonary embolism: improvement of observer agreement by the use of a lung segment reference chart. Thromb Haemost. 1992;68:245-9.
63. **Lensing AW, Büller HR, Prandoni P, Batchelor D, Molenaar AH, Cogo A, et al.** Contrast venography, the gold standard for the diagnosis of deep-vein thrombosis: improvement in observer agreement. Thromb Haemost. 1992;67:8-12.