Acute Pulmonary Embolism: Value of Transthoracic and Transesophageal Echocardiography in Comparison with Helical CT

Paul Steiner[1,2]
Gunnar K. Lund[3]
Jörg F. Debatin[4]
Dagmar Steiner[1]
Christoph Nienaber[3]
Volkmar Nicolas[1]
E. Bücheler[1]

OBJECTIVE. The goal of this study was to prospectively compare the accuracy of transthoracic and transesophageal B-mode and Doppler echocardiography with helical CT for detecting acute pulmonary embolism.

SUBJECTS AND METHODS. Thirty-five consecutive patients underwent transthoracic and transesophageal echocardiography and contrast-enhanced helical CT. Echocardiographic examinations were analyzed for indirect criteria, including increased main pulmonary artery diameter, tricuspid regurgitation, and dilatation of the right ventricular cavity, as well as for direct thrombus visualization. Sensitivity, specificity, and negative and positive predictive values were calculated.

RESULTS. Pulmonary embolism was revealed by helical CT in 22 of 35 patients; in 11 of these 22 cases, central pulmonary embolism was seen. Transthoracic and transesophageal B-mode echocardiography failed to reveal pulmonary embolism in nine patients, two of whom had central pulmonary embolism. The sensitivity and specificity of the combination of both echocardiographic investigations were 59% and 77% respectively (82% and 92% for central pulmonary embolism). In three patients, pulmonary embolism was diagnosed by direct clot detection with transesophageal echocardiography. In two patients, only the indirect parameters indicated pulmonary embolism. Overall indirect echocardiographic parameters were characterized by a low sensitivity that ranged from 50% for tricuspid regurgitation to 21% for main pulmonary artery diameter.

CONCLUSION. In comparison with helical CT, transthoracic and transesophageal echocardiography had limited accuracy for detecting pulmonary embolism.

The clinical outcome in patients with acute pulmonary embolism depends on the speed of diagnosis and therapy initiation [1]. The introduction of helical CT has facilitated the workup of patients with suspected pulmonary embolism. Although conventional contrast angiography remains the accepted gold standard in assessing pulmonary embolism, helical CT is highly accurate in detecting central and segmental pulmonary embolism [2]. Although it is considerably less invasive than conventional angiography, CT still requires the patient to be transported to and placed onto the CT scanner. Particularly in critically ill patients, a bedside evaluation for pulmonary embolism would be highly desirable.

Echocardiography has been suggested as a possible bedside alternative for assessing patients with suspected pulmonary embolism [3]. Although central pulmonary arteries can be visualized directly with transesophageal echocardiography [4], both transthoracic and transesophageal echocardiography reveal indirect signs of pulmonary embolism, including tricuspid regurgitation, right ventricular dilatation, paradoxical septal wall motion, and widening of the pulmonary artery diameter [3, 5]. Because of their noninvasive nature and the ability of transthoracic and transesophageal echocardiography to perform the study at the bedside, some investigators have promoted the use of these techniques as the first diagnostic tests in assessing patients with suspected pulmonary embolism.

The purpose of this study was to prospectively evaluate the accuracy of transthoracic and transesophageal echocardiography with

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[1]Department of Radiology, University Hospital Hamburg, Martinistr. 52, D-Hamburg 20246, Germany.

[2]Present address: MR-Center, Department of Radiology, University Hospital Zürich, CH-8091 Zürich, Switzerland. Address correspondence to P. Steiner.

[3]Department of Cardiology, University Hospital Hamburg, D-Hamburg 20246, Germany.

[4]Department of Radiology, University Hospital Zürich, Rämistr. 100, CH-8091 Zürich, Switzerland.

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regard to detecting pulmonary embolism, using helical CT as the gold standard.

Subjects and Methods

Thirty-six patients with clinical suspicion of acute pulmonary embolism were studied prospectively over the 12-month period from April 1994 to April 1995. All patients were referred with the clinically suggested diagnosis of pulmonary embolism. The clinical diagnosis was suspected on the basis of the presence of the sudden onset of dyspnea ($n = 25$), hyperventilation ($n = 12$), retrosternal pain ($n = 11$), and tachycardia ($n = 10$). In addition, blood gas values and ECG changes were taken into account as well as the presence of predisposing conditions, including malignancy ($n = 3$), major surgery ($n = 5$), and clinical evidence of a peripheral source of an embolus ($n = 4$). The clinical parameters of all patients were equivalent to the Greenfield classification of pulmonary embolism grade II–III [6]. Patients were excluded from the study based on the following criteria: cardiopulmonary insufficiency (Greenfield classification IV–V), known chronic pulmonary embolism or other known causes for elevated right ventricular pressures, and contraindications to the use of iodinated contrast agents. All patients underwent both transthoracic and transesophageal echocardiography as well as helical CT within at least 4 hr (mean, 90 min). One patient had to be excluded after both investigations had been performed. This patient revealed elevated right heart pressure due to a previously unidentified low-output left ventricle. Thus the final study group consisted of 35 patients (nine women and 26 men who were from 32 to 84 years old [mean age, 52 years]).

Helical CT

Helical CT was performed on a Somatom Plus S scanner (Siemens, Erlangen, Germany). On the basis of a scout view, we defined the outer margins of the scan volume. The acquisition volume ranged from the base of the lungs to the level of the aortic arch. One hundred milliliters of 30% iodinated contrast material (Solutrast 300 [iopamidol]; Byk Gulden, Konstanz, Germany) was injected at a rate of 2.5 ml/sec through a cannula placed in a peripheral vein. A delay of 15 sec was instituted between the start of contrast infusion and helical scanning. A collimation of 5 mm and a table feed of 10 mm/sec rendered a pitch of 2. Images were acquired with 165 mAs and reconstructed using the 180° linear interpolation algorithm. The scanning time ranged between 15 and 22 sec. Subjects were instructed to hold their breath for the required scanning time. If that was not possible, images were acquired during shallow breathing. Axial reconstructions from the helical volume were performed using 4-mm thin sections with the soft-tissue window setting and 8-mm sections using the lung window setting. A high-resolution reconstruction algorithm was chosen.

CT was investigated for direct signs of pulmonary embolism as described in detail in a previous study [7]. CT reveals thrombotic clots to the level of segmental pulmonary arteries [2]. To establish the diagnosis of hemodynamically significant pulmonary embolism and for comparison with transthoracic and transesophageal echocardiography, we determined that clot analysis to the level of the lobar arteries was sufficient. Although indirect signs of pulmonary embolism (such as diameter of the main pulmonary artery) were measured at the level of the pulmonary artery bifurcation [8], the diagnosis of pulmonary embolism by CT was based solely on direct thrombus detection. Because transesophageal echocardiography specifically detects centrally located thrombi directly, patients were divided into three groups according to CT results: group 1, no pulmonary embolism; group 2, central pulmonary embolism with thrombi positioned within the heart, the main pulmonary artery, the left or right central pulmonary arteries; group 3, all patients with positive diagnosis for pulmonary embolism as seen on CT, including those with peripherally located thrombi. CT images were interpreted by a single observer who was kept unaware of the echocardiographic data.

Echocardiography

Conventional transthoracic and color coded Doppler echocardiography were performed on a Hewlett-Packard Sonos 1000 (Hewlett-Packard, Andover, MA) interfaced with a 3.5-MHz transducer. Single-plane 5-MHz probes were used for transesophageal echocardiography. In addition to using transesophageal echocardiography to reconfirm signs of pulmonary hypertension observed by transthoracic echocardiography, we used it to screen the visualized pulmonary artery vasculature for intravascular thrombotic clots in all patients.

All investigations were videotaped and were interpreted by an experienced echocardiographer who was kept unaware of the CT results. The quality of the transthoracic and transesophageal examinations was graded on a 3-point scale: 1 = diagnostic study with good image quality, 2 = diagnostic study with moderate image quality, and 3 = nondiagnostic study.

Diagnosis of pulmonary embolism was based on the presence of one or a combination of the following echocardiographic criteria: thrombi present in the visualized segments of the pulmonary artery tree on transesophageal echocardiography; dilatation of the right ventricular cavity, which was considered to be present if the right ventricular cavity area was equal to or larger than the left ventricular area [5]; increase of the main pulmonary artery diameter beyond 3 cm at the level of pulmonary bifurcation [8]; and tricuspid regurgitant jet without inspiratory collapse of the inferior vena cava or paradoxical motion of the interventricular septum [9]. The systolic pulmonary artery pressure was calculated according to the simplified Bernoulli equation [10, 11]. Tricuspid regurgitant jet velocities of more than 3.5 m/sec (corresponding to an elevated pressure of more than 35 mm Hg) were considered pathologic.

Statistics

Sensitivity, specificity, and negative and positive predictive values for revealing pulmonary embolism were calculated for the overall assessment and for individual parameters observed by transthoracic and transesophageal echocardiography. Quantitative parameters were compared by means of the Student's t test for independent groups.

Results

All CT investigations were technically adequate and showed excellent opacification of the pulmonary vasculature. Eight patients could not hold their breath for the required imaging time. Shallow breathing did not appear to adversely affect visualization of the pulmonary vasculature. Helical CT revealed intravascular clots in 22 (63%) of 35 patients. In these 22 patients with pulmonary embolism, 70 intravascular thromboembolic clots were identified. Sixteen clots were seen in the central pulmonary arteries of 11 patients; 54 thrombi were identified in peripheral pulmonary arteries: 22 on the left and 32 on the right. The number of thrombotic clots for each patient ranged from one to seven (mean, three).

Transthoracic echocardiography was graded as diagnostic with good image quality in 14 patients, diagnostic with moderate image quality in six, and nondiagnostic in one patient. Transthoracic Doppler measurement could not be performed in six patients. Trans-esophageal echocardiography rendered diagnostic image quality in all patients (good, 28 patients; moderate, seven patients). Although the right pulmonary artery was always visualized, the entire left pulmonary artery was seen in 29 (83%) of 35 patients. Because nonvisualization of the left pulmonary artery is an anatomic rather than a technical limitation, these examinations were still graded as diagnostic. On the basis of a combination of transthoracic and transesophageal parameters, a positive diagnosis of pulmonary embolism was derived in 16 (46%) of 35 patients.

The correct diagnosis of pulmonary embolism by echocardiography in 13 patients was established solely on the basis of direct clot

visualization with transesophageal echocardiography in three patients and solely on indirect signs of elevated right heart pressure in two patients. Both direct and indirect signs were present in eight patients. Transthoracic and transesophageal echocardiography missed nine of 22 patients with pulmonary embolism, whereas three patients were graded as false-positive (Table 1). Echocardiography correctly identified nine of 11 patients with centrally located clots but missed central thrombi situated in the left-side pulmonary artery of two patients. There were five false-positive diagnoses for direct visualization of central clots by transesophageal echocardiography, three in the right pulmonary artery and two in the left pulmonary artery. In four of those false-positive diagnoses, positive indirect parameters were documented as well. In three of those five patients, CT revealed bilateral peripherally located pulmonary embolism. The remaining two patients did not show any signs of pulmonary embolism on CT and were graded false-positive for diagnosis of pulmonary embolism. The third patient graded false-positive had positive indirect echocardiographic parameters only. Sensitivity, specificity, and positive and negative predictive values for the correct diagnosis of pulmonary embolism are shown in Figure 1. Parameters of patients with central pulmonary embolism (group 2) are listed separately.

Table 2 summarizes mean values and standard deviations of pulmonary artery diameters at the level of the pulmonary bifurcation as measured by transesophageal echocardiog-raphy, as well as pressure gradients between right atrium and ventricle as measured by transthoracic echocardiography. Pulmonary diameters showed considerable overlap and were not significantly different in patients with pulmonary embolism compared with those without evidence of pulmonary embolism (group 1) ($p > .2$). However, pressure gradients were significantly higher in patients with central (group 2) or peripheral (group 3) pulmonary embolism than in patients without clots ($p < .05$). Sensitivity and specificity and positive and negative predictive values for all indirect indexes are shown in Table 3.

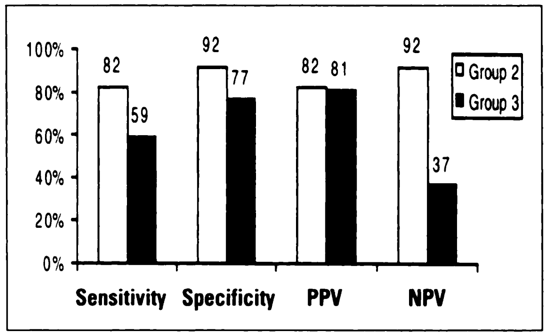


Fig. 1.—Sensitivity, specificity, and positive (PPV) and negative (NPV) predictive values for transthoracic and transesophageal echocardiography in revealing pulmonary embolism.

TABLE 1 Pulmonary Emboli Revealed by Helical CT and by Transthoracic (TTE) and Transesophageal (TEE) Echocardiography

TTE/TEE	Helical CT		
	PE +	PE −	Total
PE +	13	3	16
PE −	9	10	19
Total	22	13	35

Note.—Data are for all patients. PE + = positive for pulmonary embolism; PE − = negative for pulmonary embolism.

Discussion

In this prospective study both transthoracic and transesophageal echocardiography performed poorly at detecting pulmonary embolism. The use of transthoracic and transesophageal echocardiography as the first tool for diagnosing pulmonary embolism has been predicated on the theory that hemodynamically significant pulmonary embolism causes characteristic echocardiographic changes in patients without previous cardiopulmonary disease [12, 13]. In this respect, several characteristic indirect echocardiographic signs of pulmonary embolism have been described. The most promising of these appears to be tricuspid regurgitation, which Chapoutot et al. [5] found present in 92% of cases. Conversely, Kasper et al. [14] reported a positive incidence in only 49% of patients with acute pulmonary embolism. The sensitivity of 50% in our prospective study falls well within that range. Combined with the negative predictive value of that single indirect parameter of 50%, it is clear that the diagnosis of pulmonary embolism cannot be excluded on the basis of that criterion alone.

In our study, main pulmonary artery diameter and right ventricular size were found to be even more unreliable for revealing pulmonary embolism, with sensitivities of 21% and 31% respectively. These findings agree with the suggestion of Come [15] that the absence of indirect signs of pulmonary hypertension may reflect the inability of the previously normal nonhypertrophic right ventricle to generate a mean pulmonary artery pressure in excess of 40 mm Hg. On the basis of a combination of indirect signs, we correctly diagnosed 10 of 22 patients. These results are similar to those reported by Jardin et al. [16], who found normal echocardiographic indexes in nine of 21 patients with acute pulmonary embolism. However, Kasper et al. [14] reported a sensitivity of 85% for the combination of the same indirect echocardiographic indexes. However, that retrospective study included only patients with a known diagnosis of pulmonary embolism. The patient selection bias might have contributed to the better overall performance.

In our study, tricuspid regurgitant jet velocities were significantly higher in patients with pulmonary embolism than in patients without. However, we found considerable overlap, as evidenced by the high standard deviations. We found no significant difference in the degree of tricuspid regurgitation when patients with central pulmonary embolism were compared with all patients with pulmonary embolism. In fact, we found

TABLE 2 Mean Values and SD for Transthoracic and Transesophageal Echocardiography

Parameter	Mean ± SD		
	Group 1	Group 2	Group 3
Pulmonary artery diameter (cm)	2.6 ± 0.4	2.8 ± 0.5	2.8 ± 0.4
Pressure gradient (mm Hg)[a]	10 ± 24	32 ± 20	29 ± 24

[a]Transthoracic echocardiography only.

TABLE 3 Sensitivity, Specificity, and Positive and Negative Predictive Values for Transthoracic and Transesophageal Echocardiography

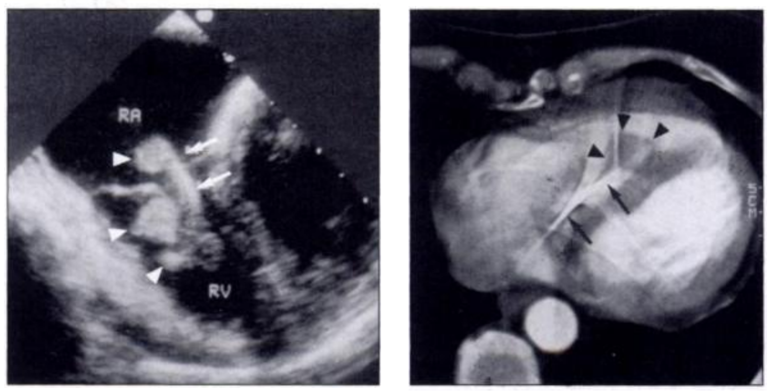
Indirect Parameter	Sensitivity (%)	Specificity (%)	Predictive Value (%)	
			Positive	Negative
Elevated pressure gradient (n = 29)	50	82	82	50
Diameter of main pulmonary artery (n = 35)	21	85	67	42
Right ventricular dilatation (n = 35)	31	85	78	42

five patients with central pulmonary embolism without any indication of tricuspid regurgitation, which is further evidence of the limited reliability of this indirect criterion.

Although transthoracic echocardiography permits only assessment of indirect signs of pulmonary embolism, transesophageal echocardiography allows visualization of the central pulmonary arteries themselves [17]. Accordingly, recent reports have described the use of transesophageal echocardiography for direct detection of central pulmonary embolism. The value of transesophageal echocardiography for the detection and characterization of intracavity clot has also been reported [14] (Fig. 2). Going beyond several case reports [18, 19], Wittlich et al. [20] reported a high diagnostic accuracy for transesophageal echocardiography in detecting central pulmonary embolism when compared with ventilation perfusion scintigraphy and pulmonary angiography, citing sensitivity and specificity of 97% and 88%, respectively. In our study, transesophageal echocardiography failed to reveal central pulmonary embolism in two patients, one of whom was not part of the group of six patients in whom visualization of the left pulmonary artery was inhibited by artifacts emanating from the left main bronchus, which runs between the esophagus and the left pulmonary artery (Fig. 3). Three of those six patients were revealed by CT to have central left-side thrombus. Only one of these studies was graded as false-negative because in the remaining two patients a concomitant right-side central clot was revealed by transesophageal echocardiography (Fig. 4). Although the right pulmonary artery seemed to be visualized adequately in all patients, central clots in three patients were not detected. In all those cases, centrally located thrombi were correctly detected on the opposite side so that, according to our interpretation, no patient was considered false-negative.

Echocardiography had higher specificity than sensitivity in revealing pulmonary embolism. Overall, echocardiography had a specificity of 77% and a positive predictive value of 81%. To a large extent, this success reflects patient selection criteria that was exercised in the current study. All patients with elevated right ventricular pressure due to other known causes were excluded. Nevertheless, we found three false-positive cases in the patient population. In two of those cases, transesophageal echocardiography revealed what seemed to be a central clot in the right pulmonary artery in one patient and in the left pulmonary artery in the other patient. One of those patients also had pathologic indirect parameters suggesting a pulmonary embolism. In the third false-positive case, our diagnosis of pulmonary embolism was based only on indirect parameters. In all three patients, no clot was revealed by helical CT.

Our study had five patients with false-positive simulation of central thrombotic

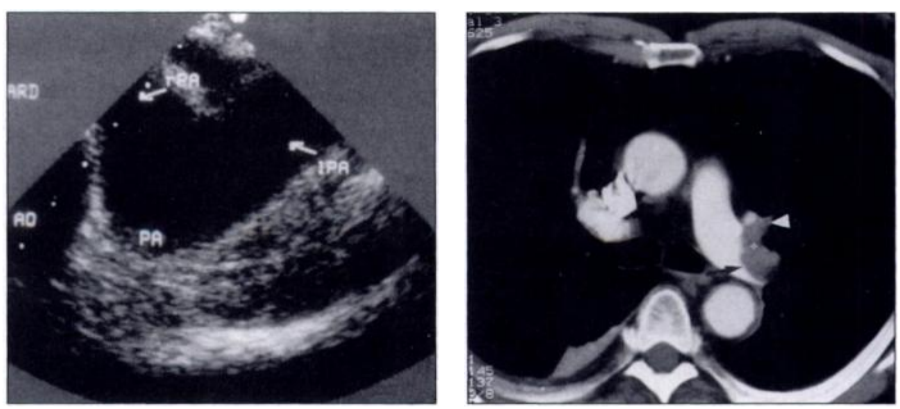


A B

Fig. 2.—54-year-old-woman with acute pulmonary embolism due to thrombotic clots affixed to intracardial electrode of pacemaker.

A, Transesophageal echocardiography reveals clots (*arrowheads*) in right ventricle (RV) and right atrium (RA). Clots are attached to wire of pacemaker electrode (*arrows*).

B, Helical CT scan shows pacemaker electrode (*arrows*) and thrombotic clot (*arrowheads*) within right ventricle.



A B

Fig. 3.—63-year-old man with central left-side pulmonary embolism. Thromboembolic clot was not revealed by transesophageal echocardiography although good visualization of left pulmonary artery was achieved. This patient also had no pathologic indirect parameters.

A, Transesophageal echocardiography shows left (lPA) and right (rPA) pulmonary arteries without direct signs of thrombotic clots. AO = aorta, PA = main pulmonary artery.

B, Helical CT scan shows soft-tissue filling defect originating in distal part of left pulmonary artery (*arrow*) and extending into left upper lobe pulmonary artery (*arrowhead*).

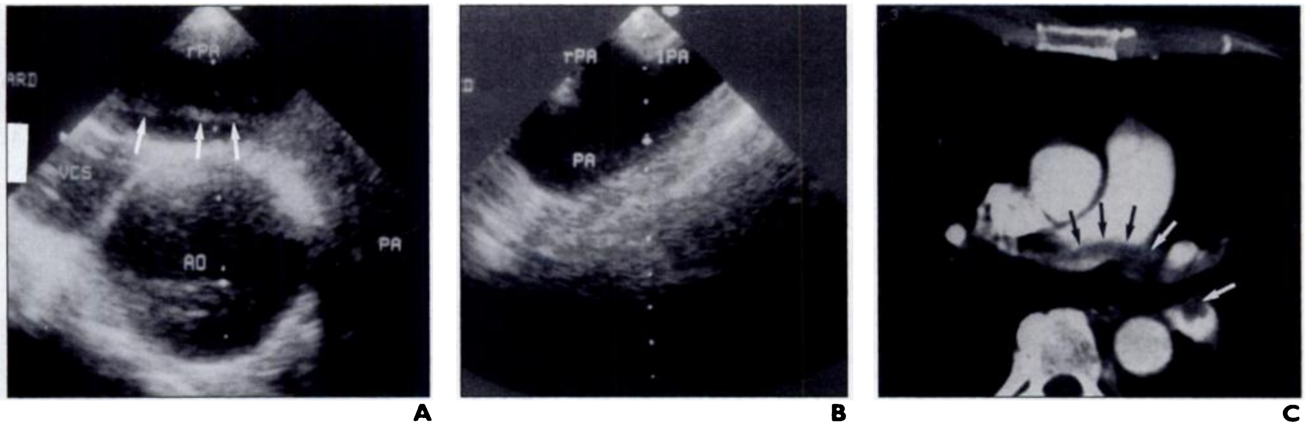


Fig. 4.—58-year-old man with central pulmonary embolism on both sides.
A, Transesophageal echocardiography shows echogenic structure (*arrows*) adjacent to right pulmonary artery (rPA). AO = aorta, PA = main pulmonary artery, VCS = superior vena cava.
B, With different projection angle, transesophageal echocardiography reveals proximal part of left pulmonary artery (lPA). Note that thrombotic clot is not visualized. PA = main pulmonary artery.
C, Axial CT image at level of pulmonary artery bifurcation shows thromboembolic clot attached to posterior wall of right and left pulmonary arteries. Note clot invades left lower lobe pulmonary artery (*arrows*).

clots. In three of these patients, helical CT that was performed shortly after transesophageal echocardiography revealed peripheral thrombi in both sides of the lung. In the time lag between echocardiography and CT, the central clots may have been dislodged. This simulation of thrombus in the proximal parts of both pulmonary arteries and the inability to detect clots in the distal parts of the main pulmonary arteries (Fig. 3) could also reflect the use of a single-plane transducer, by which a clot may be simulated if imaging is limited to one plane [5]. The use of a biplane transducer might have overcome this problem and thus contributed to a further increase in the specificity of transesophageal echocardiography for identifying central pulmonary embolism.

Indirect signs of pulmonary embolism documented with transthoracic echocardiography were also highly specific, as shown by the high positive predictive values in Table 3.

Helical and ultrafast CT can screen the pulmonary arteries for thrombi at the segmental level [2, 21, 22]. It is well documented that helical CT does fail to reveal subsegmental pulmonary emboli [23]; selective conventional pulmonary angiography still remains the gold standard. The clinical relevance of such subsegmental disease remains in question. It is estimated, however, that 95% of patients with thrombi in subsegmental regions have concomitant, more centrally located thrombi [24]. Thus, for the current study, helical CT seems well suited as the standard of reference.

The CT technique we adopted varies from other studies [21, 23] as we used a small collimation with a pitch of 2, enabling greater chest coverage during a single breath-hold. Previous studies showed that on helical CT scans of the lungs, narrow collimation and high or ultrahigh reconstruction alorithm provide the best image resolution and have more effect on image quality than choice of table speed [25]. Scans obtained using small collimation and a pitch of 1 instead of 2 revealed no difference in the visibility of peripheral vessels [25]. We agree that use of a pitch of 1 might be useful in evaluating subsegmental emboli. Because we limited the analysis in our study to central and segmental arteries, the impact of using a pitch of 2 was probably not that significant.

The combination of contrast volume, flow velocity, and 15-sec delay allowed for optimal opacification of pulmonary vasculature in all our patients. In patients with right ventricular strain and decreased right ventricular output, this delay might not be sufficient. A 20-ml preliminary bolus of contrast material with serial scans through the main pulmonary artery would show the time of maximal opacification and provide a guide for more precise timing of the final bolus.

Our study group was small. Although the high prevalence of positive findings might reflect a certain degree of selection bias, it does not impair the message of this study that neither transthoracic nor transesophageal echocardiography is particularly well suited as a diagnostic tool in assessing pulmonary embolism. The combined use of both echocardiographic methods shows advantages over either method used alone, but an overall sensitivity of 59% appears insufficient to warrant using these tests in routine clinical settings. In view of the limitations of CT in detecting subsegmental pulmonary emboli, the sensitivity might be even poorer if compared with pulmonary angiography. Moreover, negative echocardiographic examinations do not exclude central or massive pulmonary embolism, although diagnostic accuracy is higher for that patient subgroup. Accordingly, patients with echocardiographic findings negative for pulmonary embolism should undergo additional diagnostic studies. The choice of the primary diagnostic procedure for patients with suspected pulmonary embolism depends on the patient's clinical status as well as on available technology. In most patients, helical CT could be selected to establish or exclude clinically relevant pulmonary embolism [26]. Although echocardiography does not appear to be useful in assessing pulmonary emboli, the technique remains important in assessing severely ill patients to exclude other causes simulating the clinical appearance of pulmonary embo-

lism, such as right ventricular dysfunction due to myocardial injury or pericardial tamponade.

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