Sonography of Lung and Pleura in Pulmonary Embolism*

Sonomorphologic Characterization and Comparison With Spiral CT Scanning

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Study objectives: Despite the widespread use of lung scanning and angiography, pulmonary embolisms (PEs) remain undiagnosed in the majority of patients, suggesting the need for alternative diagnostic approaches. The present study investigates the clinical utility of transthoracic sonography (TS) for the diagnosis of PE and compares the data obtained with the technique to those obtained by spiral CT (sCT) scanning.

Design: This prospective study was performed using 69 patients with suspected PEs. TS was performed in all patients. In addition, sCT scanning was carried out in 62 patients. Other diagnostic procedures included the estimation of d-dimers, echocardiography, venous duplex sonography of the legs, pulmonary angiography, and ventilation/perfusion scanning. The diagnosis of PE was accepted when there was a conclusive result of these investigations or when an embolus could be visualized on a CT scan.

Setting: The Department of Pneumology in Friedrich-Schiller-University Hospital (Jena, Germany).

Patients: Sixty-nine patients (27 women and 42 men) with suspected PEs.

Results: A diagnosis of PE was established in 44 patients. Ninety-one peripheral parenchymal lesions (mean, 2.6 lesions per patient; range 1 to 9 lesions per patient) that are associated with PE were detected by TS in 35 patients (80%). Multiple, triangular, hypoechoic, and pleural-based parenchymal lesions with a localized and/or basal effusion were typical of the PEs as shown by TS. In nine patients with central PEs that had been diagnosed by CT scanning, no peripheral lesions could be detected by sonography. One patient with sonographic signs of PEs had a diffuse bronchogenic adenocarcinoma that was diagnosed at autopsy. In another patient with parenchymal lesions, pneumonia was diagnosed by CT scanning. The sensitivity of TS for detecting PEs was 80% (sensitivity of CT scanning, 82%), and the specificity of TS for detecting pulmonary lesions was 92% (specificity of CT scanning, 100%). The positive and negative predictive values of TS for the detection of PEs were 95% and 72%, respectively (positive predictive value for CT scanning, 100%; negative predictive value for CT scanning, 72%). The accuracy of TS was 84% (accuracy of CT scanning, 89%).

Conclusions: TS is a noninvasive technique that is used for diagnosing parenchymal alterations, and it may serve as an additional method in the strategy for diagnosing PE.

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Key words: pulmonary embolism; transthoracic sonography of lung and pleura; spiral CT scanning

Abbreviations: PE = pulmonary embolism; sCT = spiral CT; TS = transthoracic sonography

Pulmonary embolism (PE) is an often underestimated, underdiagnosed, and undertreated disease. It is estimated to be the third most common cause of death in the United States, accounting for up to 250,000 hospitalizations and 50,000 deaths each year.1 Only one third of PEs that are confirmed by autopsy are diagnosed before death,2–7 reflecting the difficulty in establishing the diagnosis. In addition, despite the widespread use of lung scanning and angiography,8,9 there has been no significant reduction in mortality from PEs throughout the past 40 years.10
Since the signs and symptoms of PE may be silent or nonspecific, diagnosis still remains a challenge to the attending physician and requires a high index of clinical suspicion as well as a rational approach to testing. More specific investigations such as imaging techniques, however, differ significantly with respect to sensitivity and specificity, and, in the majority of cases, a negative result to testing does not fully exclude PE. Ventilation/perfusion scanning, for instance, has a high sensitivity for PE but lacks anatomic resolution and sufficient specificity. In addition, transthoracic echocardiography can easily and rapidly show the presence and the degree of right ventricular pressure overload, and may directly demonstrate thrombotic masses in the main pulmonary arteries, although sensitivity and specificity are low. MRI offers both morphologic and functional information on lung perfusion and right heart function, but its image quality still needs improvement. Finally, pulmonary angiography, albeit accurate, is an invasive procedure associated with low but still not negligible morbidity and mortality. In addition, the availability is limited, and nondiagnostic results may be obtained.

In the past 10 years, spiral CT (sCT) scanning has been introduced for the diagnosis of acute and chronic PEs, and it provides a noninvasive means of detecting acute PEs and organized thrombi, as well as perfusion abnormalities and other concomitant findings. However, since PEs in subsegmental pulmonary arteries are not reliably visualized, CT imaging is less accurate than angiography for detecting a minor embolism or an embolism in the stages in which central emboli have been dissolved by endogenous fibrinolysis. Thus, although sCT scanning offers a high sensitivity and specificity for central or segmental PEs, more peripheral thromboembolic lesions confined to the subsegmental level may be overlooked. Moreover, CT imaging is costly and usually requires time-consuming organization prior to the investigation. Thus, the development of alternative, easily accessible methods for diagnosis that are immediately available to the physician at the bedside, and that both facilitate recognition and reduce the time lag until diagnosis of PE can be established, is warranted.

The detection of thromboembolic lesions of the lung by sonography was first described some 30 years ago. Although the sonographic accuracy was > 90%, these early reports appear to have been overlooked for many years. More recently, Mathis and colleagues have confirmed the original results. Despite this, no other group, to date, has used a similar approach and has confirmed the data in a large prospective trial.

Thus, the rationale underlying the present study was to assess the diagnostic accuracy of transthoracic sonography (TS) in patients with suspected PEs and to compare the results with sCT scanning. A further aim of the study was to analyze the morphometric features of embolic parenchymal lesions that are associated with PE.

Materials and Methods

Patients

Between February 1998 and March 2000, a total of 69 consecutive patients (27 women and 42 men; mean age, 62.8 years; age range, 24 to 88 years) with clinical signs of PE were enrolled in the study. Only those patients were included on whom TS as well as CT scans had been performed within 24 h. During the study period, 138 patients with suspected PEs were investigated with sCT scanning but did not undergo TS.

All patients had a typical history of PE with the acute onset of complaints that included dyspnea, pleuritic chest pain, hemoptysis, vertigo or syncope, and/or tachypnea. Patients were examined by chest radiographs (n = 69), echocardiography (n = 47), sCT scanning (n = 62), ventilation/perfusion scanning (n = 23), ECG (n = 69), venous duplex sonography of the legs or contrast venography (n = 61), and pulmonary angiography (n = 2). The diagnostic procedures also included the estimation of d-dimer levels (NycoCard; Immuno; Heidelberg, Germany).

TS

TS was conducted using a 5-MHz and 3.5-MHz convex scanner, which occasionally was supplemented by examination with a 7.5-MHz linear scanner or in color flow Doppler mode (AU5 Harmonic; Esaote Biomedica; Munich, Germany). TS was performed by one independent physician who was trained in chest sonography and who was unaware of the results of other diagnostic procedures. TS was conducted with the patient seated by an intercostal application of the scanner by (1) assessing the intercostal areas where the patients localized the pain followed by (2) a systematic examination of the remaining intercostal spaces. Suspicious lesions were assessed along the longitudinal and transverse axes. Where required, the intercostal space was increased by placing the patients’ hands behind the head and elevating the elbow.

sCT Scanning

Sixty-two patients also underwent sCT scanning (Somatom Plus 4; Siemens; Erlangen, Germany) [3-mm section thickness, 3-mm to 4-mm increments, and pitch 2]. The CT image was read by an expert in chest radiology. In seven cases, this method was not available, and in four cases the diagnosis could be primarily established. In two patients, extreme overweight and a known allergy for the contrast medium precluded the performance of a CT scan. The diagnosis of the condition of the remaining patient was confirmed by autopsy.

Diagnostic Criteria

A diagnosis of PE was accepted if PEs could be detected by sCT scanning. When parenchymal lesions were detected on sonography only (n = 7) or if sCT scanning was not available (n = 7), the diagnosis of PE was accepted when at least
three of the following five investigations yielded positive results: (1) typical history (see above); (2) echocardiography; (3) venous duplex sonography or contrast venography of the legs; (4) ventilation/perfusion scanning; and (5) d-dimer level.

sCT scans were analyzed for the presence of intraluminal filling defects, defects within the central pulmonary arteries, dilatation of the main pulmonary arteries, and decreases in the size of the small branches of the lung as well as irregularities of the blood vessels.24

RESULTS

TS

Of the 69 patients enrolled in this study, 44 (63.8%) had experienced PEs. Among the 44 patients, 35 (80.0%) showed sonographic changes involving the lung parenchyma (Table 1). The parenchymal lesions were assessed according to their shape, number, size, demarcation, movement during respiration, and the detection of a single central echo. Lesions also were analyzed using color Doppler imaging. In addition, the pleura were analyzed with respect to the continuity of the visceral pleural line and the widening of the local and basal pleural space.

Nine patients (25.7%) had only one parenchymal lesion, whereas the remaining 26 patients (74.3%) suffered from multiple lesions. In total, 91 peripheral lesions were detected by TS (mean, 2.6 lesions per patient; range, 1 to 9 lesions per patient). The most typical parenchymal findings were the following: (1) wedge-shaped or rounded (Fig 1, 2) hypoechoic lesions; (2) hypoechoic lesions that extended to the pleural surface and, in most cases, were well-demarcated; and (3) occasionally a single echo that could be detected in the center of the lesions (Fig 1).

Parenchymal lesions detected by chest sonography had an average size of 13.8 × 10.6 mm (size range, 3.7 × 3.9 mm to 60 × 70 mm). Ten of the 91 lesions (11%) were rounded, and 3 lesions (3.3%) had polygonal configurations. Most of the hypoechoic areas (78 areas; 85.7% of lesions) were wedge-shaped (Fig 2). All lesions were hypoechoic and showed a convex outward bulging of the pleura. In six cases, a hyperechoic single echo was seen in the center of the lesions (Fig 3). All areas showed free movement during respiration.

Characteristic signs of the pleural involvement included the following: (1) a widening of the pleural space corresponding to the parenchymal lesion due to the local accumulation of fluid; (2) a widening of the basal pleural space as a consequence of basal effusion with the patient in the upright position; (3) a convex outward bulging of the pleura; and (4) a thinned and fragmented hypoechoic visceral pleural line. Localized effusion was seen in eight patients (22.9%), and another seven patients (20.6%) showed basal effusions. In six patients (17.1%), both localized and basal effusions could be detected (Fig 3).

Nine patients who had no lesions from peripheral PEs revealed by TS had severe central PEs detected by CT scanning. Four of these patients (44.4%) showed localized effusions, and in one patient (11.1%) a localized and a basal effusion were apparent. Another patient revealed sonographic features that were suggestive of pneumonia with a corresponding pleural effusion.

The results of TS were truly negative in 23 patients without PEs. Nine patients without lesions shown on TS had severe central PEs detected by CT. One patient with sonographic signs of a PE had a diffuse bronchogenic adenocarcinoma that was diagnosed at autopsy. In another patient with sonographic findings that were suspicious of PE, pneumonia was diagnosed by CT scanning. The sensitivity of the TS for PEs was 80%, and the specificity was 92%. The positive and negative predictive values of TS for the detection of a PE were 95% and 72%, respectively. The accuracy of TS for the detection of a PE was 84% (Table 2).

sCT Scanning

Intraluminal filling defects of the central pulmonary arteries were detected in 32 of 39 patients (82%) on sCT scans. In seven patients without central embolisms shown on sCT scans, the final diagnosis of PE was made on the basis of the other examinations performed. All seven patients had typical hypoechoic lesions seen on TS. sCT scanning was truly negative in 23 patients without PEs (Table 1). Because of these results, the sensitivity of helical sCT scanning for predicting PEs was 82%, and the specificity was 100%. The positive and negative predictive values were 100% and 77%, respectively. The accuracy of helical sCT scanning for predicting PEs was 89% (Table 2).

DISCUSSION

Despite the advent of new techniques such as contrast-enhanced sCT scanning, diagnosing PEs

**Table 1—Results of TS in Comparison With sCT in 69 Patients With Suspected PE**

<table>
<thead>
<tr>
<th>Results</th>
<th>TS (n = 69)</th>
<th>sCT (central changes) (n = 62)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct positive</td>
<td>35</td>
<td>32</td>
</tr>
<tr>
<td>False-positive</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>False-negative</td>
<td>9</td>
<td>7</td>
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<tr>
<td>Correct negative</td>
<td>23</td>
<td>23</td>
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still remains a significant medical problem, accounting for a considerable number of deaths each year. Moreover, only one third of PEs confirmed at autopsy are diagnosed before death, suggesting that a high percentage of PEs continue to remain undiagnosed. On the other hand, the early accurate diagnosis of PE is important and potentially lifesaving. The reasons for this discrepancy between the incidence of PE and its diagnostic confirmation are multifold. One cause may relate to the fact that decisions about patients with suspected PEs need to be made in real time and that the time available for decision making is short. Moreover, diagnostic techniques such as ventilation/perfusion scanning, CT scanning, or angiography may not be immediately at hand, and may, furthermore, require time for arranging an examination and for the transport of the patient, thus delaying appropriate treatment decisions. Thus, alternative, easily accessible methods that would be available immediately to the physician at the bedside are needed both to facilitate recognition of PEs and to reduce the time lag until a diagnosis of PE can be established. The data presented herein demonstrate that PEs may be diagnosed by TS, which is widely available, easily accessible, and can be performed at the bedside without delay.

Figure 1. Representative sonograms of parenchymal and pleural alterations that are associated with PE. Top, A: two triangular hypoechoic pleura-based parenchymal lesions. The upper one contains a single centrally located echo. Top middle, B: two rounded, hypoechoic pleura-based parenchymal lesion. Bottom middle, C: a small, wedge-shaped hypoechoic parenchymal lesion with widening of the adjacent pleural space representing a localized pleural effusion. Bottom, D: an sCT scan that corresponds to that shown in the top middle, B, panel. Filling defects within the left lower pulmonary arteries (arrows) confirm the diagnosis of PE. Pleural effusions are shown on both sides.

Figure 2. The frequency of the shape of hypoechoic lesions in a PE that was detected using TS. The data shown are based on a total of 91 embolic lesions that were detected in 35 patients with confirmed PEs. See the text for further details.
In our study, a diagnosis of PE was accepted if PEs could be detected by CT scanning or as a result of clinical assessments, including patient history, echocardiography, venous duplex sonography, contrast venography of the legs, ventilation/perfusion scanning, and d-dimer level measurement. Pulmonary angiography was required in two patients in whom the diagnosis of PE remained unclear. Among the 44 patients with established PEs, 35 (80.0%) showed peripheral lesions on TS of the lung parenchyma. In two patients, a diagnosis of PE by TS could not be confirmed by autopsy in one patient (diffuse bronchogenic adenocarcinoma) or CT scanning in the other patient (pneumonia). These data correspond to an 80% sensitivity of TS for PE and a 92% specificity of TS for PE. The results are in agreement with previously published values for the TS diagnosis of PE. Moreover, the sensitivity of TS is comparable with that shown for CT scanning (sensitivity range, 75 to 92%). Although the number of patients enrolled in the study is low and future prospective studies are warranted, the data suggest that TS represents a reliable technique for diagnosing PEs, with a sensitivity that is compatible with that obtained by CT scan assessment.

It is important to distinguish pulmonary and pleural lesions identified by sonography from lung carcinomas lesions or metastases, pneumonic lesions, and scarring tissue. In one patient with PE that was confirmed by CT scanning, sonographic changes that were compatible with pneumonia accompanied by pleural effusions were observed. In this patient, clinical symptoms had commenced 2 to 3 weeks prior to hospital admission. Although this case led to a false-positive sonographic evaluation, it stresses two important aspects of TS. First, TS may provide valuable information in cases in which complications related to PE develop. Second, the case underlines the importance of a rapid and immediate diagnostic confirmation when PE is suspected.

PE is a sudden thrombotic occlusion of a pulmonary artery involving variable areas of lung parenchyma depending on the size of the artery involved. The sudden complete embolic clog of a pulmonary artery results in a rapid breakdown of the surfactant system, which promotes not only atelectasis but also the transudation of fluid and the migration of cells into the affected lung tissue. As a consequence, these pathophysiologic alterations lead to a depletion of air allowing ultrasound waves to penetrate the affected parenchymal lung region. The data presented herein demonstrate that during sonography these thromboembolic lesions characteristically appear as well-demarcated, pleura-based, mostly triangular, but also circular, hypoechogenic areas.

The data also suggest, that in the majority of cases, PEs involves multiple sites within the peripheral lung parenchyma. Seventy-five percent of patients with PEs showed two or more lesions (mean, 2.6 lesions per patient; range, 1 to 9 lesions per patient). The number of lesions is in good agreement with previous studies that reported an average of 2.7 lesions per patient, as detected by pulmonary angiography (range, 1 to 16 lesions per patient), and 2.6 lesions per patient, as detected by TS (range, 1 to 7 lesions per patient). Whether these lesions result from a single embolic event or are due to recurrent embolic episodes remains unknown.

The study provides evidence that a central PE is often accompanied by a peripheral PE. In addition, the data also suggest that even in the absence of a major thrombus in the main pulmonary artery, small peripheral localized lesions may be present. Peripheral consolidations in association with PE also have been described in sCT scans, but their diagnostic meaning is not fully understood. Although it would be interesting to directly compare position, size, and morphology of the lesions detected by both imaging
techniques, the primary aim of this article was to assess parenchymal lesions by sonography as diagnostic criteria for a thromboembolic event.

The clinical importance of peripheral emboli is still a matter of controversy. While some authors consider minor PEs to be clinically irrelevant, others have suggested that minor embolic events may represent a first “warning” signal preceding further thromboembolic events. In view of the fact that PEs, in the majority of cases, are diagnosed postmortem, it may be necessary to consider even the smallest peripheral lesion as being a potentially serious event requiring rigorous treatment in order to reduce mortality due to PE. In addition, in patients with preexisting cardiopulmonary disorders, even a minor PE might cause severe cardiorespiratory deterioration. Since TS can distinguish parenchymal lesions of <1 cm, it represents an ideal method for the detection of small or very small peripheral thromboembolic events.

Patients experiencing thromboembolic events often present with pleuritic chest pain suggesting indirect pleural involvement. Here, alterations of the pleura and the pleural space, including widening of the pleural space due to localized effusion or basal effusions, were observed in 60.6% of all patients with confirmed PEs. In addition, a convex outward bulging of the pleura, and a thinned and fragmented hypoechoic visceral pleural line adjacent to the parenchymal lesion represented a regular feature. Thus, data obtained by TS provided a rather detailed picture of both the parenchymal and pleural alterations following thromboembolic occlusion of pulmonary arteries, and they suggest an involvement of the pleura in approximately half of the patients.

There are however, a number of natural restrictions to TS that limit its diagnostic potential. First, embolism-associated lesions can be detected only when they extend to the lung periphery. Second, a mere 66% of the peripheral lung area is accessible to sonographic examination, the remainder being covered by bony structures. Third, TS is subjective and operator-dependent, relying on the experience of the examiner. The above reasons may explain the <100% sensitivity of detecting PEs by TS. Inconspicuous sonographic findings do not fully exclude a PE.

A limitation of our study is the use of sCT scanning as the comparative standard. Indeed, the diagnostic significance of detecting peripheral emboli by sCT scanning has yet to be established. However, in order to compensate for the potential lack of sensitivity and specificity of CT scanning, the diagnosis of PE also was accepted when the results of at least three of the additional investigations (ie, medical history, echocardiography, venous duplex sonography or contrast venography of the legs, and ventilation/perfusion scanning or d-dimer level measurement) were positive.

In all, a substantial number of PE events extend to the peripheral lung areas and can, thus, be detected by applying TS. TS is a simple, widely available, easily accessible, noninvasive, and cost-effective diagnostic technique providing a useful additional method for the diagnosis of PE. Moreover, TS allows for frequent noninvasive monitoring of the course of the disease as well as the early detection of subsequent complications, such as postinfarction pneumonia, that may arise. TS represents an alternative diagnostic method in cases in which PE is suspected. However, future prospective studies comparing the diagnostic usefulness of TS and sCT scanning are warranted.

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