CORRELATION OF PULMONARY PHOTOSCAN AND ANGIOGRAM AS MEASURES OF THE SEVERITY OF PULMONARY EMBOLIC INVOLVEMENT

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Both experimental and clinical correlations of the relative value of lung scans and pulmonary angiograms for the detection of pulmonary embolism (PE) have been reported (*1,2*). Differences in specificity and sensitivity of each method at various anatomic levels of the pulmonary arterial bed have been emphasized. Despite these differences the two techniques have been shown to be reasonably comparable in the detection of PE, particularly when each method is considered in light of its inherent limitations (*1,2*). A numerical expression of their comparability in assessing the magnitude of embolic involvement has not been reported. The clinical importance of establishing the extent of embolic involvement has recently been emphasized by studies which have shown that the severity of the hemodynamic abnormality after embolism can be directly related to the magnitude of the defect as estimated by both angiography (*3*) and lung scanning (*4*). The present report examines the comparability of the two methods in assessing the extent of embolic involvement in patients without underlying cardiopulmonary disease.

MATERIALS AND METHODS

This study includes 14 patients in whom the diagnosis of PE was established by both lung scan and selective pulmonary angiography. Underlying cardiopulmonary disorders were carefully excluded by history, physical examination, baseline or recovery ECG, chest x-ray, and pulmonary function tests in the recovery period. Only patients with the diagnostic criteria of intravascular filling defects or cutoffs by selective angiography (*5,6*) were admitted to the study. Angiographic studies were generally performed within 24–48 hr of the clinical suspicion of PE and within 4 hr of pulmonary photoscanning. All patients were male. Underlying diagnoses are shown in Table 1.

Four-view lung scans (anterior, posterior, right and left laterals) were obtained using a dual 5-in. Ohio Nuclear detector scanner. Iodine-131-macroaggregated human serum albumin from Mallinckrodt or ^{99m}Tc-macroaggregated human serum albumin from Cambridge Nuclear was administered through a peripheral vein after dose was normalized for body weight. The pulmonary photoscans were evaluated with simultaneously obtained standard chest x-rays. The technique for estimating the extent of perfusion impairment has been described in detail (*4*). Briefly, the pulmonary photoscans were evaluated with 6-ft films (antero-posterior and lateral) obtained in the supine position on the scan table. After overlying the scans upon the chest films, the projected 100% perfusion area was traced on all views and quantified by planimetry. The sum of the planed areas was equated to 100% normal perfusion. Defects were determined by planimetry in a similar manner and the total perfusion defect was expressed in percent.

An Eppindorf catheter was used for selective pulmonary angiography. Films were obtained in the antero-posterior projection using a Schonander rapid film changer. The method for estimating the extent of embolic involvement angiographically has also been described in detail (*3*). In summary, the magnitude of embolic involvement was estimated on the angiogram by dividing each lung field into halves and assigning a value of 25% to each. A region of opacified, uninvolved lung was selected to compare the decrease in angiographic opacification of the involved lung to estimate the degree of total pulmonary vascular involvement. In addition, each lung was divided into four groups of arterial branches and the presence or absence of a vessel cutoff or a filling

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TABLE 1. DIFFERENCES IN EMBOLIC INVOLVEMENT BY LUNG SCAN AND ANGIOGRAPHY IN INDIVIDUAL PATIENTS

Case No.	Age	Diagnosis	% involvement		Absolute differences		% difference	
			Angio	Scan	Angio>Scan	Scan>Angio	Angio>Scan	Scan>Angio
1	37	Pulmonary embolism	13	20		7		53
2	24	Chronic venous insufficiency, lower extremities	15	18		3		20
3	50	Pulmonary embolism	23	45		22		95
4	56	Osteoarthritis left hip, status post arthroplasty	25	13	12		92	
5	48	Pulmonary embolism	31	18	13		72	
6	47	Thrombophlebitis pulmonary embolism	32	45		13		40
7	45	Pulmonary embolism	40	62		22		55
8	43	Glioblastoma multiformans	47	50		3		6
9	69	Vasculitis, unknown cause	48	35	13		37	
10	49	Peripheral vascular disease, status post ileofemoral endarterectomy	51	45	6		13	
11	31	Fractured right fibula	53	39	14		35	
12	18	Regional enteritis	55	52	3		5	
13	26	Status post arthrotomy, left knee	60	60	0	0	0	0
14	52	Retroperitoneal sarcoma	68	54	14		25	
Mean			40.1	39.7	9.4	10.0	34.9	38.4
s.d.			17.2	16.5	5.6	9.2	32.4	33.1

Columns from left to right indicate case number, age and diagnosis of patient, and percent involvement by embolism as determined by pulmonary angiogram and lung scan. The absolute difference between the angiogram and the scan (larger value minus smaller) is shown in the next two columns. The last two columns indicate percentage difference in the scan and angiogram estimates, calculated as absolute difference divided by the smaller estimate.

defect was used to estimate the degree of total pulmonary vascular involvement.

The lung scans and angiograms were evaluated and scored independently by each investigator. All scans and angiograms were designated by code so that the patient was unknown to the investigator. The scans and angiograms of each patient were evaluated independently of one another.

RESULTS

It became apparent early in a series of "practice" readings that agreement between investigators was close for both scans and angiograms in patients without underlying cardiopulmonary disease (within 10%). It was considered that the interpretation of acute abnormalities superimposed upon a normal pulmonary vascular tree was likely to result in significantly less reader disagreement than would be observed in patients with underlying cardiopulmonary disease.

A good correlation between the two methods was observed when the entire population was examined ($r = 0.712$, $p < 0.01$, Fig. 1). Involvement was greater by angiography in seven patients and by lung scan in six patients (Table 1). Both techniques showed the same involvement in one patient. The mean value for the absolute difference (9.4%) and the percentage difference (34.9%) by which the angiogram exceeded the scan estimate in seven patients was comparable to the absolute difference (10.0%) and percentage difference (38.4%) by which the lung scan estimate was greater in six patients (Table 1). Angiographic estimations of pulmonary vascular occlusion averaged 40.1% (range 13–68%) while estimations by lung scan averaged 39.7% (range 13–62%).

The greatest variability between the two methods was observed with lesser degrees of involvement by either method. When angiography estimated a defect less than 40%, the scan defect usually exceeded involvement estimated by angiography (4 of 6 patients, Table 1). When angiographic estimates exceeded 40%, the lung scan usually showed lesser degrees of impairment of perfusion (5 of 7 patients, Table 2). Significant exceptions to this general pattern existed, however. Even though the angiogram demonstrated a greater degree of involvement in only 2 of 6 patients with angiographic involvement less than 40%, the percent differences between the two techniques were substantial in those two patients (92 and 72%; Cases 4 and 5). Absolute differences were small (12 and 13%), however, being only

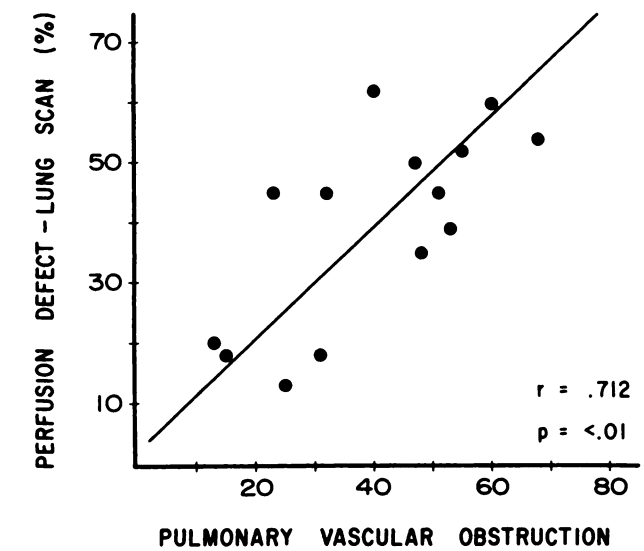

FIG. 1. Relationship between estimated embolic involvement by lung scan, expressed in percent on vertical axis, and angiogram, in percent on horizontal axis, is shown.

slightly in excess of reader variability, so that the percentage error appeared greater because the absolute involvement was small by both graphic techniques. Similarly, the lung scan showed a greater degree of involvement in only 2 of 7 patients when angiographic involvement exceeded 40%. In only one (Case 7) was the absolute difference significant (22%). In the other (Case 8), the absolute difference (3%) was well within the range of reader variability.

DISCUSSION

The importance of an accurate assessment of the extent of embolic involvement. When the magnitude of angiographic involvement is related to the hemodynamic abnormality after PE in previously normal patients, a predictable relationship is observed (*3*). Systemic arterial hypoxemia is generally the only abnormality until angiographic obstruction exceeds 25%. As obstruction increases from 25 to 50%, pulmonary hypertension occurs and progresses, followed by proportionate elevations of right heart filling pressure. Angiographic obstruction in excess of 50% is usually present before cardiac output is impaired. A similarly predictable relationship has been shown between the perfusion defect by lung scan and the hemodynamic disturbance in patients free of underlying cardiopulmonary disease (*4*). When pulmonary embolism complicates underlying cardiopulmonary disease, however, it is often difficult and may be impossible to establish which process is the major cause of the hemodynamic impairment. The interaction of PE with severe underlying cardiopulmonary disease is poorly understood. Now that the hemodynamic abnormality has been shown to be related to the magnitude of embolic involvement, however, some basis for determining the extent to which an underlying cardiopulmonary process may be contributing to the hemodynamic abnormality after PE is available. The present study compares the fidelity with which perfusion scanning and angiography measure the extent of embolic involvement.

Although the lung scan examines the integrity of capillary flow while the angiogram is best at detecting embolic material in larger vessels, Fig. 1 indicates that scan and angiogram correlated reasonably well in the assessment of embolic involvement in the population as a whole. In general, however, the extent of embolization was best demonstrated by the perfusion scan when the overall magnitude of embolism was less than 40%, while with more extensive involvement, the angiogram appeared to be more reliable. Agreement between the two techniques was closest when massive clot (seen as filling defects)

TABLE 2. DIFFERENCES IN EMBOLIC INVOLVEMENT BY LUNG SCAN AND ANGIOGRAPHY AMONG PATIENTS WITH OBSTRUCTION GREATER AND LESS THAN 40%

	Angio involvement	Scan involvement	Absolute differences Angio>Scan	% differences Angio>Scan	Absolute differences Scan>Angio	% differences Scan>Angio
(A) Patients with angio involvement < 40%	23.2 ± 7.9* (6)†	26.5 ± 14.5 (6)	12.5 ± 0.7 (2)	82.0 ± 14.1 (2)	11.3 ± 8.3 (4)	52.0 ± 31.7 (4)
(B) Patients with angio involvement > 40%	52.8 ± 8.5 (8)	49.6 ± 9.5 (8)	8.3 ± 6.2 (6)	19.2 ± 15.5 (6)	8.3 ± 11.9 (2)	20.3 ± 30.2 (2)

* Mean and s.d.

† Number of patients.

The mean values for angiographic involvement and scan involvement are shown in columns 2 and 3, respectively, while the mean value of the absolute differences and percentage differences are shown in columns 4 and 6, and 5 and 7, respectively. Horizontal line 1 shows the values for patients with angiographic involvement less than 40%, while horizontal line 2 indicates values when angiographic involvement exceeds 40%.

completely obstructed either a part of the main pulmonary artery or the junction of main and lobar pulmonary arteries (Cases 8, 12, 13; Figs. 2, 3). Lung areas supplied by the vessels involved with the massive central clots shown in Figs. 2 and 3 showed virtually complete obstruction both angiographically and by scan, and angiographic involvement exceeded 40% in each case. In addition, perfusion defects correspond closely to the location of angiographic obstruction and perfused areas correspond well to areas of opacified pulmonary arterial branches. Large discrepancies between the two techniques were noted in other patients, however, and deserve individual consideration.

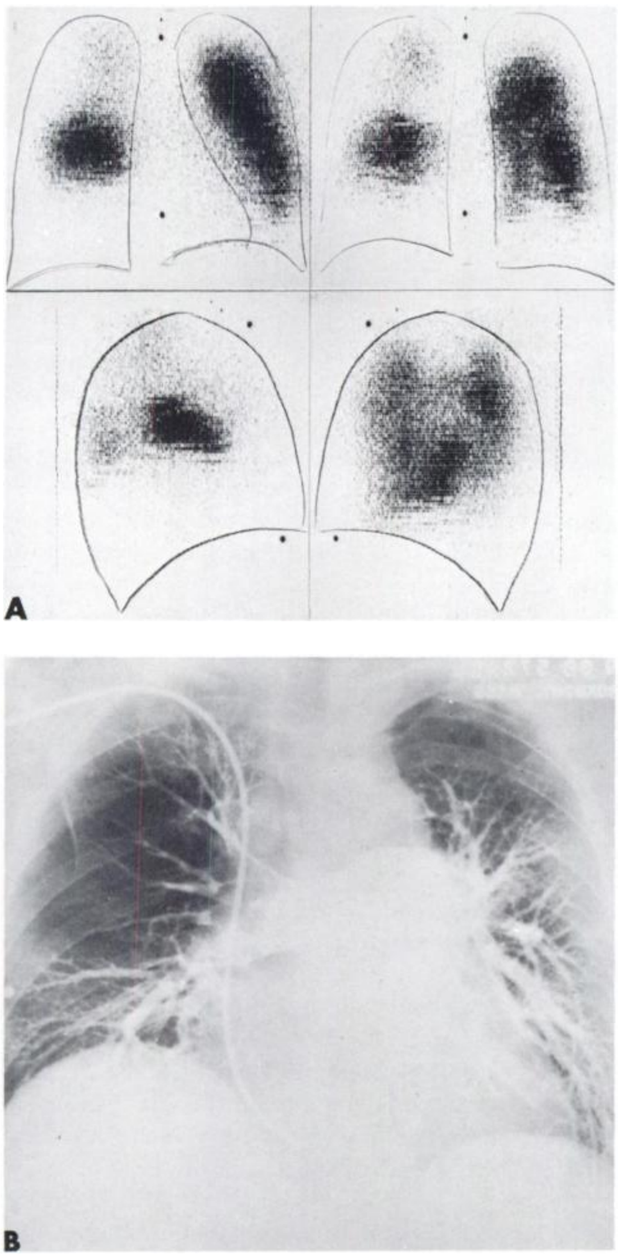

FIG. 2. Case 8: Lung scan involvement as seen by four-view scan (A) and angiographic involvement as seen in antero-posterior projection (B) are shown in patient in whom involvement, estimated independently by each technique, is almost identical; i.e., lung scan 50% angiogram 47%. Note large filling defect involving nearly entire right main pulmonary artery, with elevation of right hemidiaphragm and loss of vascularity to lower third and most of upper half of right lung. There is also absence of vascularity angiographically at left apex along periphery of left midlung field and at left base. Lung scan shows excellent correlation with angiographic involvement. Four views include anterior (A_{I}), posterior (A_{II}), right lateral (A_{III}), and left lateral (A_{IV}).

Angiographic obstruction in excess of perfusion defect by lung scan. As noted above, the level of comparability between the two techniques clearly appeared to be determined by the magnitude of embolism and the completeness of vascular obstruction. As a general rule, when angiography detected involvement of 40% or more, the lung scan usually showed lesser degrees of involvement than the angiogram (Table 1). Angiographic estimates exceeded those by scan particularly when large emboli lodged in the main pulmonary artery or lobar branches. Obstruction in this circumstance may be incomplete, so that the resultant flow to the subserved area may appear relatively normal by lung scan. Fred et al (*1*) reported that the lung scan failed to indicate accurately either the location or the extent of angiographically proven PE in 5 of 27 patients (19%). Furthermore, in the same study perfusion abnormalities were restricted to one side in some patients despite multiple, bilateral emboli shown angiographically. With flow around the angiographically visible embolism, the scan remained relatively normal, so that the extent of involvement assessed angiographically exceeded that seen by perfusion scanning. One case in which estimated angiographic involvement (68%) exceeded the scan defect (54%) is shown in Fig. 4 (Case 14). While the gross difference is relatively small (14%), it exceeded the range of reader variability. In addition, the defect by both graphic techniques was massive (>50%), further suggesting that the percentage difference of 25% may be significant.

Scan defects in excess of angiographic obstruction. Tow and Wagner (*7*) reported that 65% of patients with PE had more than one underperfused area by lung scan. Experimental studies by Moser et al (*2*) and Dalen et al (*8*) showed that fragmentation of emboli characteristically occurred, suggesting that the multiple areas of underperfusion observed by Tow and Wagner may have been due to fragmentation. Distribution of clot between proximal and distal vessels depends on the size of the embolus and the degree of fragmentation. When fragmentation is relatively complete, large central emboli will not be observed by angiography, and embolic involvement of smaller vessels will predominate. Since obstruction of smaller vessels is more likely to be complete (*2,9*), lung scan defects are more likely. With

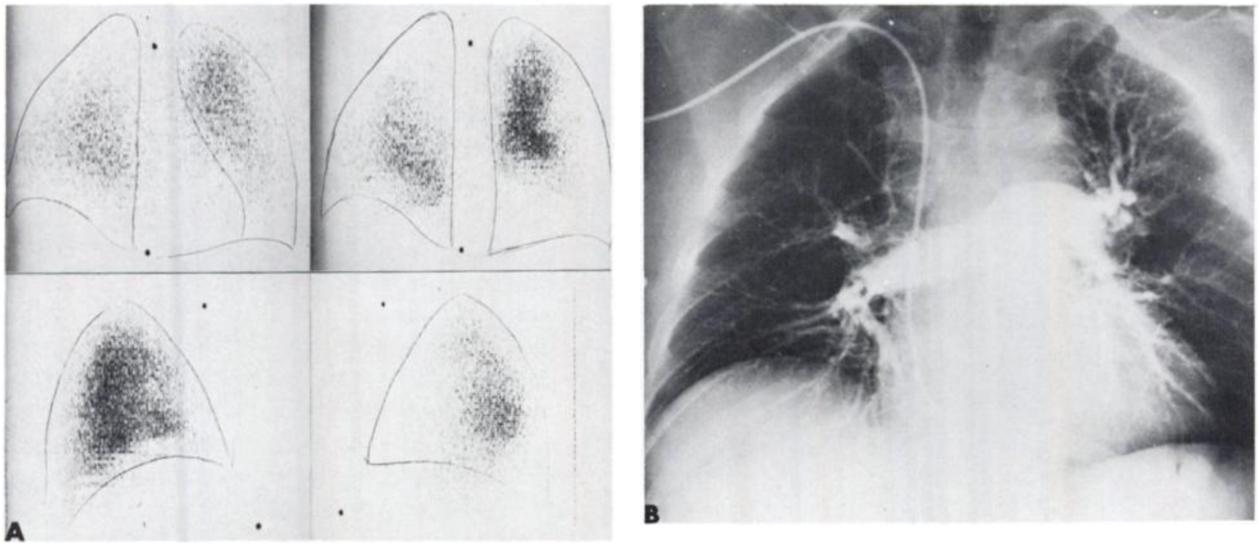

FIG. 3. Case 12: Lung scan (A) and angiogram (B) again show massive embolic involvement. Angiogram reveals bilateral massive filling defects, involving junctions of main pulmonary artery and lobar branches on both sides. Lung scan views are arranged as in Fig. 1. Lung scan involvement was estimated at 52%, angiographic involvement at 55%. Areas of angiographically patent vasculature correlate well with perfused areas by scan. Large discrepancies between two techniques were noted in other patients.

involvement of smaller vessels, however, the angiogram becomes less reliable: both the failure to detect clot that is present and false positive diagnoses increase (*2*). When emboli are small or fragmentation is extensive, then, the lung scan may be expected to be more reliable in accurately assessing the extent of embolic involvement. The present study supports this view. With lesser degrees of embolic involvement (angiographic involvement less than 40%, scan involvement 45% or less; Table 1), the scan detected more extensive involvement in 4 of 6 patients. Case 3 is an example of the scan detecting more extensive involvement (Fig. 5). A filling defect can be seen in the posterior division of the right lower lobe artery but no main or lobar pulmonary arterial involvement could be demonstrated angiographically. Other angiographic abnormalities were present but were predominantly at the segmental arterial level. Angiographic involvement was estimated at 23%. The lung scan, on the other hand, was diffusely abnormal, with a perfusion defect estimated at 45%. The differences in the extent of involvement appeared to be attributable to the fact that PE either fragmented extensively or occurred as multiple showers of small emboli, resulting in involvement of vessels beyond the resolution capabilities of angiography (2 mm vessels) but susceptible to detection with capillary perfusion techniques.

Masking of filling defects by the density of overlying contrast media has been observed (*10*) and may be noted when occlusion is incomplete, so that the embolism may be effectively insulated and obliterated except in one or several films. Incomplete obstruction often results in a diminution of radioactivity in the subserved region but does not result in a cold spot distally. In such circumstances, the embolic mass is likely to be underestimated by both graphic techniques. This phenomena has been shown experimentally (*2*).

Methodologic difference in the determination of the extent of embolic involvement by scan and angiogram. Lung scan defects were estimated from both anterior and posterior scans. The magnitude of involvement by angiography, on the other hand, was estimated from a single antero-posterior view with maximal opacification. Underestimation by angiography of a defect whose major projections were in the sagittal plane could have resulted. The comparison between the two techniques in terms of estimating the location and extent of the defect did not show this to be an important factor, however, probably because the angiogram displayed abnormalities of individual arterial branches, thus tending to produce a three-dimensional interpretation of the single A-P view. The total angiographic defect could then be expressed as the ratio of involved branches to those not involved. The chief blind areas in the A-P angiogram are the branches running perpendicular to the plane of the film so that, being seen only on the end, the degree of involvement may not be apparent.

It was concluded that the scan and angiogram correlate closely in the individual patient only when embolic involvement is extensive and complete obstruction of larger vessels (filling defects) is detectable angiographically. Since the angiogram is usually more accurate in detecting more extensive obstruction, while the scan is more sensitive to smaller more peripheral emboli, an accurate estimate of the mag-

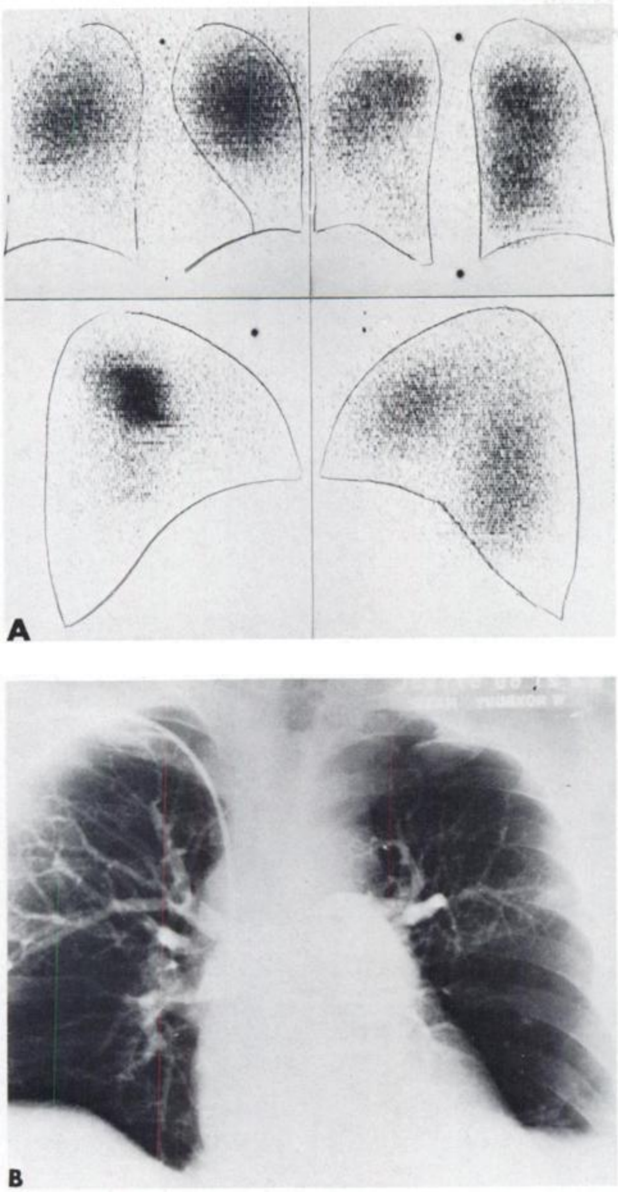

FIG. 4. Case 14: Patient was huge man (280 lb) with massive chest and significant elevation of diaphragm. Estimated involvement by lung scan (A) was 54%, while by angiography it was 68%. While absolute error was relatively small in view of range of variability between readers, percentage difference was substantial (25%).

nitude of embolic involvement in the individual patient may require both techniques.

SUMMARY

The observation that the hemodynamic impact of pulmonary embolism usually is directly proportionate to the extent of embolic obstruction by angiography and the extent of the perfusion defect by lung scan has emphasized the importance of an accurate assessment of the magnitude of embolic involvement. This may prove to be particularly true in patients with underlying heart or lung disease in whom the contribution of embolism to the hemodynamic abnormality may be very difficult to define. The extent of embolic involvement as assessed by pulmonary photoscanning was compared to the assessment by selective pulmonary angiography in patients free of underlying cardiopulmonary disease. The two techniques correlated reasonably well in this group of patients ($r = 0.712$; $p < 0.01$). There was significant variability among individual patients, however. When large central emboli were present and produced complete obstruction, the correlation be-

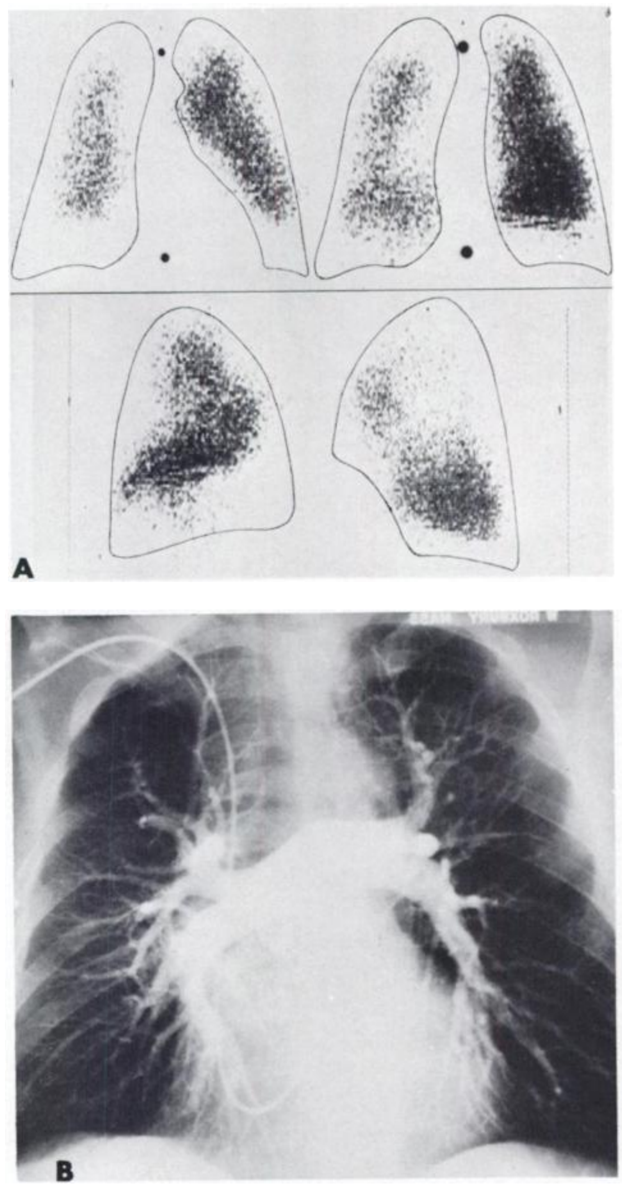

FIG. 5. Lung scan views are arranged as in previous figures (A). Filling defect can be seen in right lower lobe vessel, but no other major filling defect was noted by angiography. Angiogram was somewhat over penetrated, but multiple smaller vessel abnormalities, with cutoffs, are apparent bilaterally, particularly in upper and lower one-third of right lung field and in lower two-thirds of left lung field. Lung scan estimate of involvement, at 45%, significantly exceeded involvement estimated by angiography (23%), however. Left lateral view further demonstrates importance of four-view scanning; defects not appreciated on anterior or posterior view are apparent on left lateral view.

tween scan and angiogram was very close. When large central emboli were present but failed to obstruct the distal vessel completely, the perfusion scan underestimated the defect seen angiographically. When small, distal embolism occurred, whether single or multiple, the angiogram underestimated the extent of embolic involvement. When overall embolic involvement was extensive (greater than 40% angiographic obstruction), the angiographic assessment was greater; with lesser degrees of obstruction, the scan assessment was greater. It was concluded that, although the overall correlation between the two techniques was good, either technique could significantly underestimate the magnitude of embolic involvement so that the use of both techniques may be essential to determine the extent of embolic involvement with reasonable accuracy.

REFERENCES

1. Fred HL, Burdine JA, Gonzales DA, et al: Arteriographic assessment of lung scanning in the diagnosis of pulmonary thromboembolism. *New Eng J Med* 275: 1025–1032, 1966

2. Moser KM, Harsanyi P, Rius-Garriga G, et al: Assessment of pulmonary photoscanning and angiography in experimental pulmonary embolism. *Circulation* 39: 663–674, 1969

3. McIntyre KM, Sasahara AA: The hemodynamic response to pulmonary embolism in patients with underlying cardiopulmonary disease. *Amer J Cardiol*, in press

4. McIntyre KM, Sasahara AA: Hemodynamic alterations related to extent of lung scan perfusion defect in pulmonary embolism. *J Nucl Med*, in press

5. Sasahara AA, Stein M, Simon M, et al: Pulmonary angiography in the diagnosis of thromboembolic disease. *New Eng J Med* 270: 1075–1081, 1964

6. Stein PE, O'Connor JF, Dalen JE, et al: The angiographic diagnosis of acute pulmonary embolism: Evaluation of criteria. *Amer Heart J* 73: 730–741, 1967

7. Tow DE, Wagner HN: Recovery of pulmonary arterial blood flow in patients with pulmonary embolism. *New Eng J Med* 276: 1053–1059, 1967

8. Dalen JE, Haynes FW, Hoppin FG, et al: Cardiovascular responses to experimental pulmonary embolism. *Amer J Cardiol* 20: 3–9, 1967

9. Moser KM, Miale A: Interpretive pitfalls in lung photoscanning. *Amer J Med* 44: 366–376, 1968

10. Freeman LM, Zelefsky MN, Kaplan N, et al: Diagnosis of pulmonary embolism with scanning and angiographic techniques: A correlative study. *J Nucl Med* 9: 394–401, 1968