Scintillation Scanning of Lungs in Diagnosis of Pulmonary Embolism

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[WITH SPECIAL PLATE BETWEEN PAGES 206 AND 207]

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Scintillation scanning of the lungs with ^{131}I-macroaggregated human serum albumin (^{131}I-MAA) was shown by Taplin *et al.* (1964) to be a safe and effective way of demonstrating pulmonary perfusion. Since then others (Haynie *et al.*, 1965; Quinn *et al.*, 1964; Sabiston and Wagner, 1964; Wagner *et al.*, 1964a) have confirmed the value and safety of this method in the diagnosis of pulmonary embolism and also explored its use in several other conditions.

^{131}I-MAA can be prepared with little difficulty from ^{131}I-human serum albumin, though it is not produced commercially in this country. The lungs receive a dose of approximately 2 rads after the intravenous injection of 300 μCi ^{131}I-MAA.

Harper *et al.* (1965) described the use of technetium-99^{m}-labelled macroaggregated human serum albumin (^{99m}Tc-MAA) for lung scanning. This substantially reduces the radiation dose to the lungs, for they receive approximately 0.3 rad after the intravenous injection of 2 mCi ^{99m}Tc-MAA, which is similar to the dose received during a chest radiograph. ^{99m}Tc with a half-life of six hours has a gamma-ray emission at 140 KeV, making it especially suitable for scintillation scanning.

The radioactive macroaggregates, which measure 20–100 μ in diameter, become impacted in the small pulmonary arterioles and capillaries after intravenous injection. The distribution of these particles is proportional to pulmonary blood flow at the time of injection and so is related to posture, as can be readily demonstrated by automatic scintillation scanning (Tauxe *et al.*, 1967). The biological half-life of the particles within the lungs ranges from two to eight hours. They are steadily broken up and pass through the pulmonary capillaries, to be removed from the circulation by the reticuloendothelial system.

Since November 1966 ^{99m}Tc-MAA has been used at University College Hospital for scintillation scanning of the lungs. This paper describes the use of this technique in patients suspected of having pulmonary embolism.

Material and Methods

Labelled macroaggregates must be prepared each day that lung scans are required, as the short half-life of ^{99m}Tc precludes their use after 12 hours.

Preparation of ^{99m}Tc-MAA.—^{99m}Tc-MAA is prepared by the method of Gwyther and Field (1966). ^{99m}Tc is eluted from a column of molybdenum-99 with normal saline as $^{99m}TcO_4^-$. This is reduced by $FeCl_3$ and ascorbic acid in the presence of N HCl. The *p*H is then adjusted to 5.6 with N NaOH. This solution is added to 1% human serum albumin and the *p*H reduced to 2.5. Labelling is virtually instantaneous. The *p*H is readjusted to 5, and the labelled solution, after the addition of carrier human serum albumin, is sterilized by millipore filtration. Macroaggregation takes place when this solution is agitated at 100 oscillations per minute in a water-bath at 75–80° C. for 15 minutes. Free pertechnetate is removed after centrifugation, and the activity of the particles is measured in an ion chamber. Normal saline is added to produce a final concentration of 1.5–2 mCi/ml. Particle size is checked by microscopy, and a sample from each batch is kept for sterility tests. The preparation takes less than 60 minutes.

Scanning Procedure.—Each patient is given 1.5–1.75 mCi ^{99m}Tc-MAA intravenously while lying supine and breathing more deeply than usual. Scintillation scanning is carried out at once by a Picker Magnascanner Mark III with a 3 by 2 in. (7.5 by 5 cm.) (thallium-activated) sodium iodide crystal and a 19-hole focusing collimator. The pulse height analyser is set at 120–160 KeV. Scanning is performed at 100–120 cm. per minute with a line spacing of 0.4 cm., starting at the lower border of the lungs. The time constant is set at 0.04 second and the background cut-off at 20% of the maximum count rate. Anterior, posterior, and occasionally lateral scans are performed, each view taking 15 to 20 minutes to complete. Colour scans and photoscans are produced simultaneously.

Results

Lung scans have been carried out on more than 200 occasions. Table I shows the indications for lung scanning, the majority of scans being done for suspected pulmonary embolism. Table II shows the number of patients that have had repeated lung scans, the interval between scans ranging from 3 days to 10 months.

TABLE I.—*Indications for Lung Scanning*

Indications for Scanning	No. of Patients Scanned	No. of Repeated Scans
Suspected pulmonary embolus	100	33
Neoplasms of the bronchus	44	7
* Other conditions	33	3
Total	177	43
Total scans	220	

* Other conditions include normal individuals, patients with chronic bronchitis and emphysema, bronchiectasis, asthma, post-irradiation pulmonary fibrosis, tuberculosis, sarcoidosis, pleural thickening, thoracoplasties, chronic rheumatic heart disease, congenital heart disease, cardiomyopathies, and collagen diseases.

TABLE II.—*Repeated Lung Scans*

No. of lung scans	2	3	4
No. of patients	22	9	1

No untoward reactions of any kind have been observed after the administration of ^{99m}Tc-MAA. Patients with massive pulmonary embolism and cor pulmonale have been scanned with no deterioration in their condition. Several patients have been scanned while on continuous monitoring of their pulse, central venous pressure, blood pressure, and electrocardiogram with no observable change in any of these factors. No allergic manifestations have been seen.

Table III summarizes the results of patients suspected of having pulmonary emboli. A lung scan was regarded as normal when there were no irregularities in the pattern of perfusion and the distribution of activity matched that seen in the lung scans of healthy individuals. A lung scan was classified as

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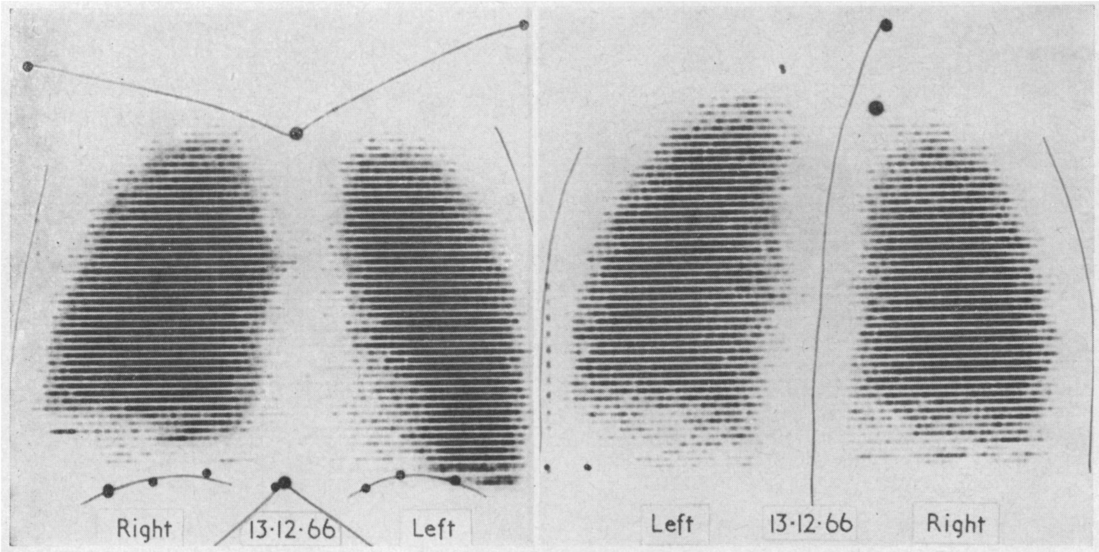


FIG. 1.—Anterior and posterior lung scans of healthy individual.

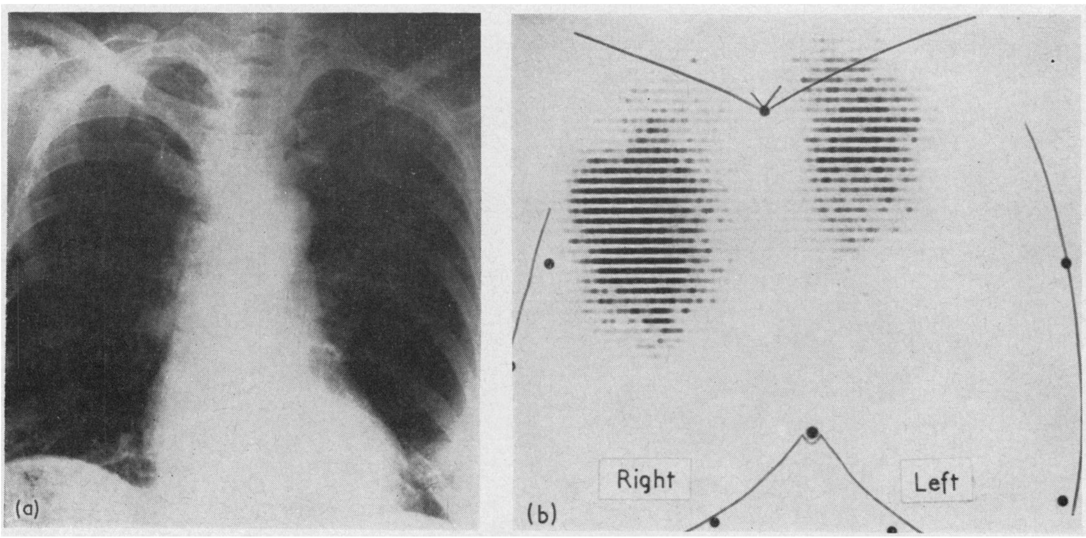
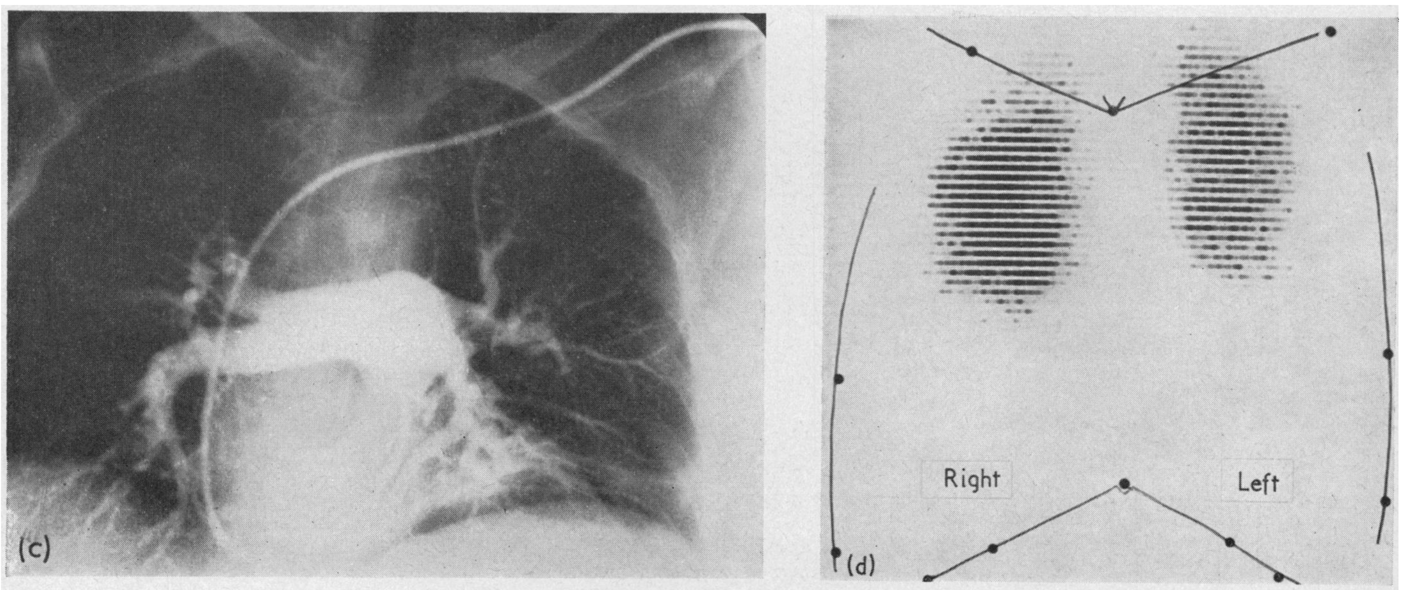


FIG. 2.—Case 1. (*a*) Chest radiograph on 11 February 1967, showing small opacity in left lower zone. (*b*) Anterior lung scan three days later, showing several areas of poor perfusion in each lung. (*c*) Pulmonary angiogram, 20 February, showing an embolus at bifurcation of left pulmonary artery. (*d*) Anterior lung scan eight days after first scan, showing some improvement of perfusion in both lungs.



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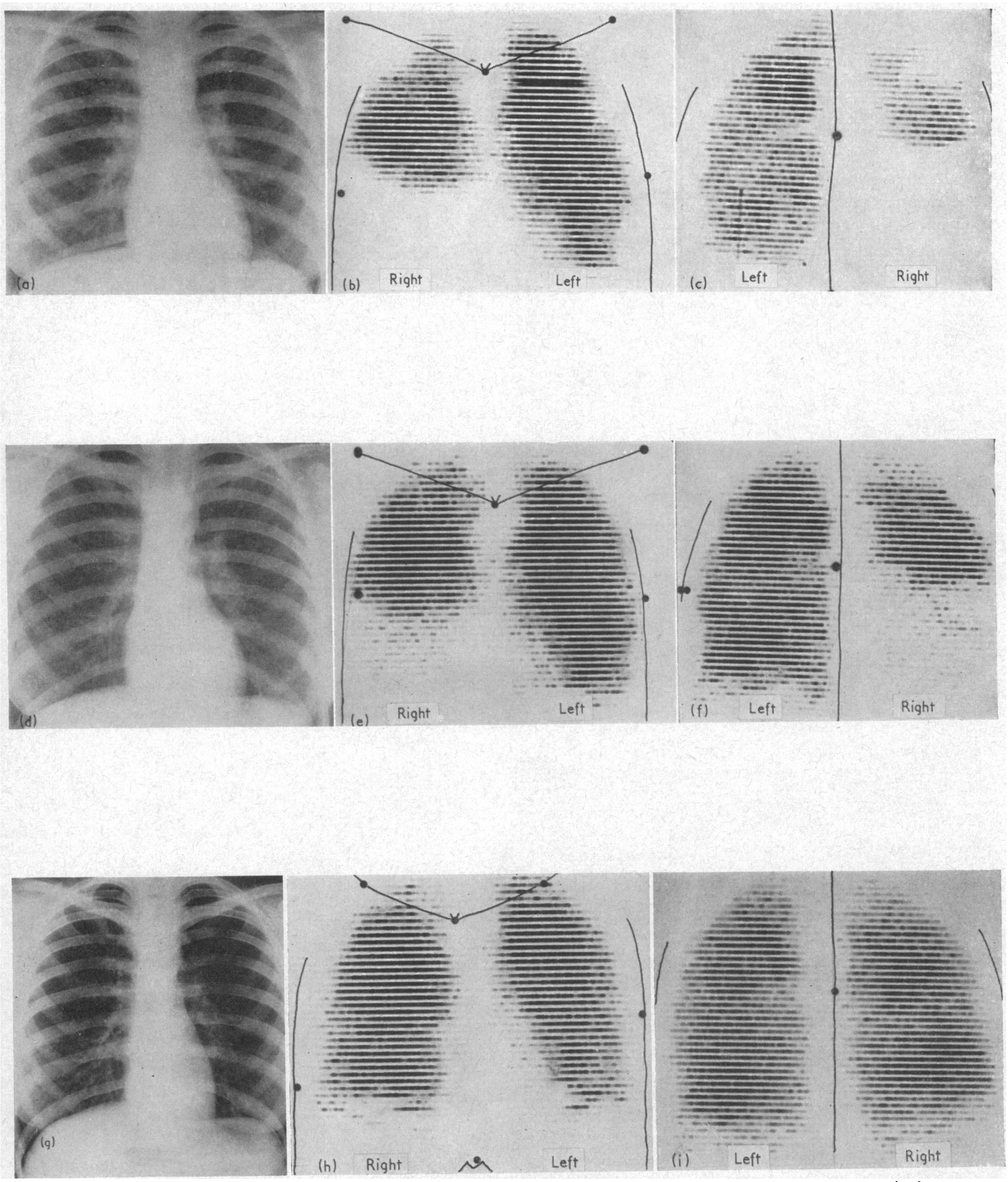
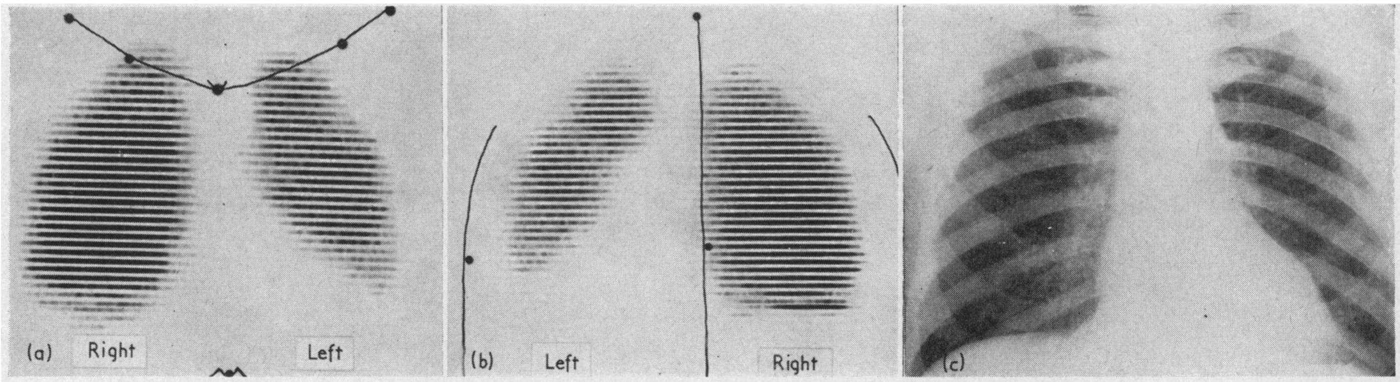


Fig. 3.—Case 2. (*a*) Chest radiograph on day of collapse and admission to hospital, 19 April 1967. (*b*) and (*c*) Anterior and posterior lung scans, showing widespread defects in pulmonary perfusion, 25 April. (*d*) Chest radiograph remains unchanged, 26 April. (*e* and *f*) Anterior and posterior lung scans, showing some improvement of pulmonary perfusion, 9 May. (*g*) Chest radiograph, 30 June, showing a reduction in heart size. (*h* and *i*) Anterior and posterior lung scans showing further improvement of perfusion of right lung, 8 August. Several small areas of decreased perfusion remain.



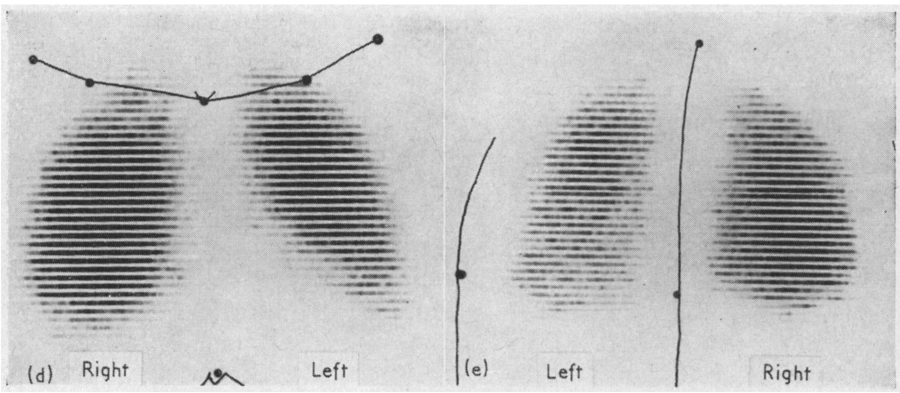


FIG. 4.—Case 3. (*a* and *b*) Anterior and posterior lung scans shortly after a pulmonary embolus to left upper and lower lobes. (*c*) Chest radiograph two days later, showing small linear shadow at left base. (*d* and *e*) Anterior and posterior lung scans eight days after embolus, showing improved perfusion of left upper and lower lobes.

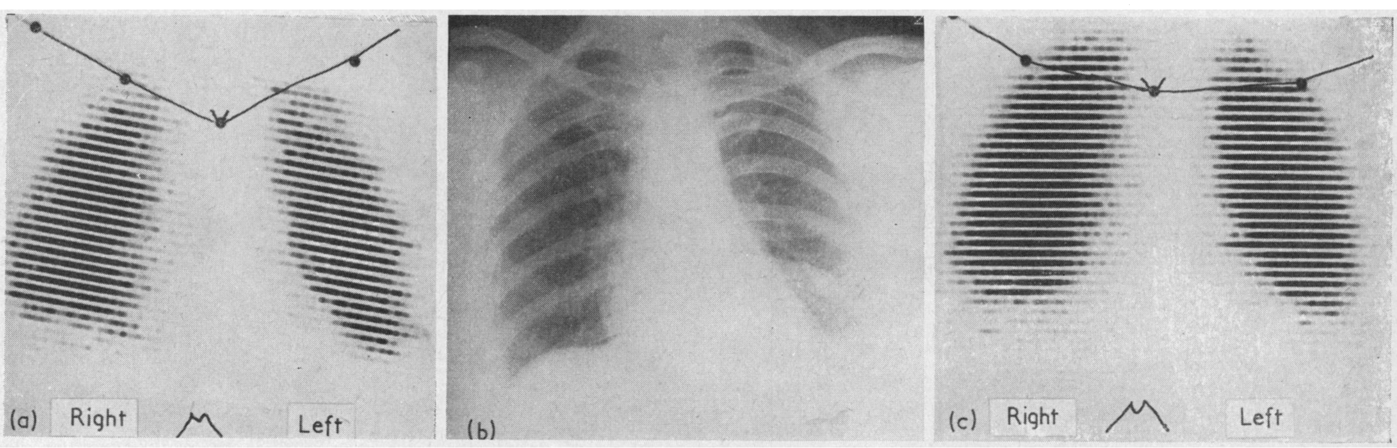


FIG. 5.—Case 4. (*a*) Anterior lung scan after collapse with suspected massive pulmonary embolus, 31 July 1967. (*b*) Chest radiograph two days later, showing no abnormality (unchanged from portable chest radiograph of 31 July). (*c*) Anterior lung scan eight days after first lung scan, showing no change.

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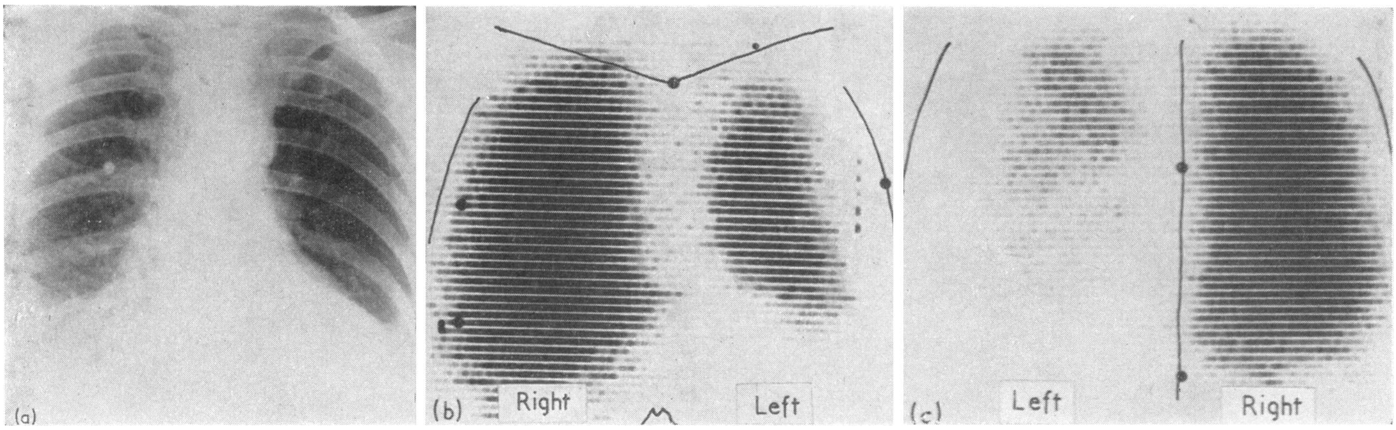

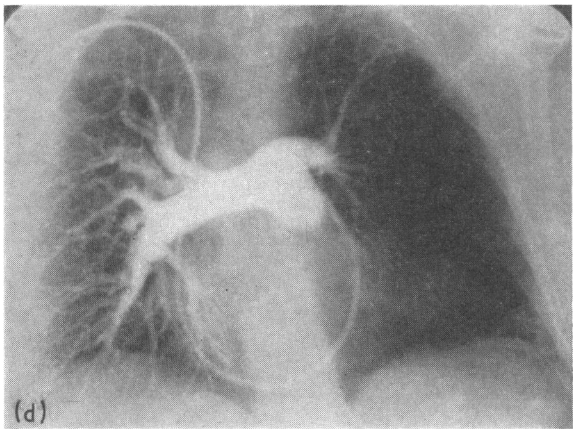

FIG. 6.—Case 5. (*a*) Chest radiograph on admission, 14 January 1967. Oligaemia of most of left lung. (*b* and *c*) Anterior and posterior scans, 17 January. Reduced perfusion of both left upper and left lower lobes. (*d*) Pulmonary angiogram showing small left pulmonary artery and branches, 30 January.

N. CONWAY *ET AL.*: CARDIAC FAILURE AFTER USE OF PROPRANOLOL

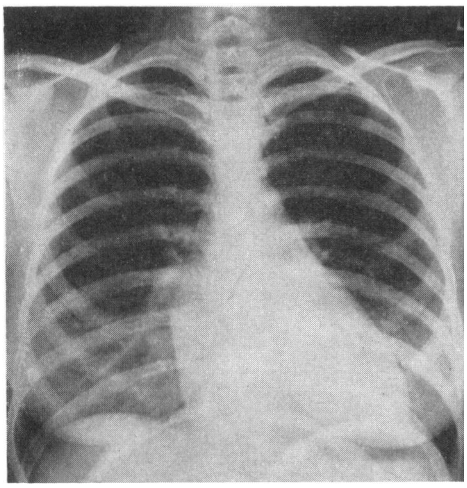

FIG. 1.—Case 2. Chest radiograph on first admission, showing heart size and configuration before propranolol.

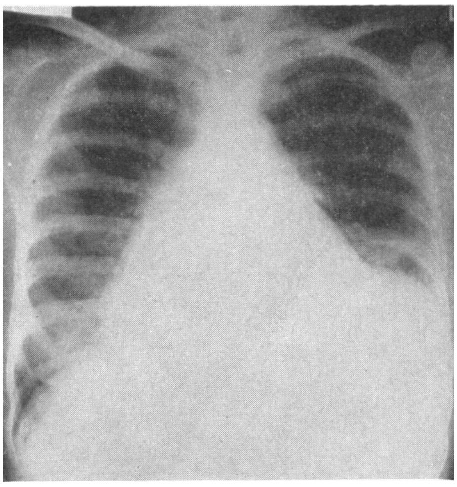

FIG. 2.—Case 2. Chest radiograph showing cardiomegaly and pulmonary venous congestion.

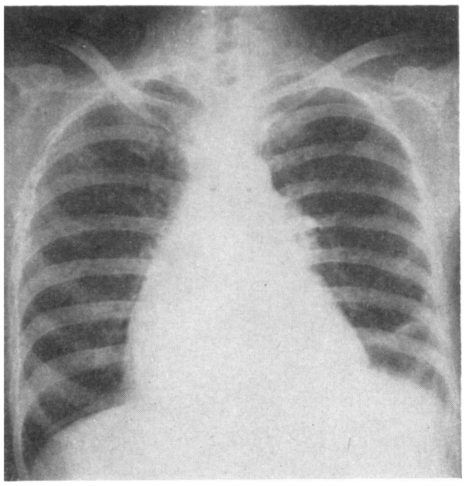

FIG. 3.—Case 2. Chest radiograph 13 days later, after withdrawal of propranolol.

"abnormal" when there were obvious defects in perfusion, ranging in size from segmental to almost total absence of perfusion of an entire lung. Scans classified as "pulmonary hypertension" showed a redistribution of blood towards the apices with the lung outlines preserved but no other localized abnormality. "Slightly abnormal" scans showed minor irregularities in the pattern of perfusion of doubtful significance.

TABLE III.—*Results in 100 Patients Suspected of Having Pulmonary Embolism*

	Lung Scan*			
	Abnormal	Pulmonary Hypertension	Slightly Abnormal	Normal
No. of patients ..	50	10	18	22

* The criteria used for assessing the lung scans are described in the text.

Lung scanning contributed to the diagnosis of pulmonary embolism in 72% of these patients, being consistent with it in 50% and excluding it in 22%. In 10% of patients the scan suggested the presence of pulmonary hypertension without much evidence of pulmonary emboli, while in a further 18% it was of no diagnostic value.

In the 50 patients in whom the lung scan was abnormal and consistent with a diagnosis of pulmonary embolism, four were subsequently diagnosed as suffering from other conditions—two from McLeod's syndrome, as a result of childhood pneumonia (see Case 5), one from bronchial asthma, and one from a subphrenic abscess. Three of the 10 patients whose lung scans suggested the presence of pulmonary hypertension also had one or more minor abnormalities in the scans consistent with small emboli; three suffered from chronic bronchitis and emphysema, three from chronic rheumatic heart disease, and one from a ventricular septal defect. Seven of the 18 patients whose lung scans were only slightly abnormal were thought by their physicians to have had pulmonary emboli; two had bronchitis, but a definite diagnosis was not established in the remainder.

Normal anterior and posterior photoscans are shown in Fig. 1 (Special Plate), the subject being a healthy volunteer.

The following case histories illustrate the value and some of the limitations of lung scanning in patients suspected of having pulmonary embolism.

Illustrative Cases

Case 1.—A married woman aged 55 developed minimal signs of a deep-venous thrombosis 11 days after a cholecystectomy. Five days later she had a pulmonary embolus. Her electrocardiogram was normal. Her chest radiograph (Special Plate, Fig. 2a) showed a small wedge-shaped opacity in the left lower lobe, and a lung scan (Fig. 2b) showed absent perfusion of the left lower lobe, reduced perfusion of the left upper lobe, and irregularities in perfusion of the right lung. A pulmonary angiogram (Fig. 2c) confirmed the site of the major embolus, and a second lung scan (Fig. 2d) showed improvement in perfusion of both lungs.

Case 2.—A housewife aged 29 was taking an oral contraceptive pill. A fortnight before admission she had been ill with chickenpox. Shortly after her recovery she had a brief episode of breathlessness and left-sided chest pain, and the next day felt very ill and dyspnoeic and then collapsed. On admission to hospital she was no longer dyspnoeic. Her blood pressure was normal and her jugular venous pressure was not raised. There was no gallop rhythm and no abnormal signs in the chest. Her electrocardiogram showed an S_1 Q_3 pattern, and next day the T waves were inverted over the right ventricle. Her chest radiograph was normal and remained so (Special Plate, Fig. 3a and d). Pulmonary embolism was suspected and she was treated with heparin followed by warfarin. A lung scan carried out a week after her admission showed absent perfusion of the right middle and lower lobes and diminished perfusion of the right upper lobe (Fig. 3b and c). Several areas of diminished perfusion were present on the left side. A second lung scan two weeks later showed some improvement in perfusion of both lungs (Fig. 3e and f). Three months later another lung scan showed considerably improved perfusion on the right side, but several areas of impaired perfusion were still present on both sides (Fig. 3h and i). A fourth lung scan seven months after the initial episode showed no further change.

Case 3.—A man aged 51 developed signs of a deep-venous thrombosis 11 days after an operation for renal artery stenosis. Four days later he had a brief episode of central chest pain and dyspnoea. There was no change in his physical signs nor in his electrocardiogram. A lung scan (Special Plate, Fig. 4a and b) showed absent perfusion of the left lower lobe and impaired perfusion of the left upper lobe. Fig. 4c shows the chest radiograph two days later, and Fig. 4d and e a second lung scan showing improved perfusion of the left lung.

Case 4.—A married woman aged 39 collapsed with chest pain, dyspnoea, and hypotension. An electrocardiogram and chest radiograph (Special Plate, Fig. 5b) were normal. A lung scan (Fig. 5a) showed small lung fields, but no localized defects in perfusion. She was thought to have septicaemia, and recovered rapidly on treatment with ampicillin. A second lung scan (Fig. 5c) was unchanged.

Case 5.—A married woman aged 63 had left-sided pleuritic pain and swelling of the left ankle for three days. Coarse crepitations and a pleural rub were heard at the left base. The electrocardiogram suggested myocardial ischaemia. Her chest radiograph showed oligaemia of most of the left lung (Special Plate, Fig. 6a). A lung scan (Fig. 6b and c) showed absent perfusion of the left lower lobe and reduced perfusion of the left upper lobe, and was unchanged after nine days of anticoagulation. A pulmonary angiogram (Fig. 6d) showed a small left pulmonary artery with small branches, but no signs of pulmonary embolism. These changes were thought to be secondary to a severe pneumonia in childhood.

Comment on Illustrative Cases

Cases 1 and 2 demonstrate the way that lung scanning can highlight the extent of the perfusion defect in pulmonary embolism, which in both patients was considerably greater than could be predicted from their chest radiographs.

Case 3 shows the magnitude of the disturbance in pulmonary blood flow that can occur with only transient symptoms and no abnormal signs. Here perfusion of the left lower lobe was greatly reduced and that to the left upper lobe was also impaired.

Case 4 illustrates the value of this technique in excluding the diagnosis of pulmonary embolism, while Case 5 shows that lung scanning only demonstrates the relative distribution of pulmonary blood flow. In addition, the failure of the scan to change after nine days is most unusual in patients with pulmonary embolism.

Discussion

Pulmonary embolism occurs with considerable frequency in medical, surgical, and gynaecological patients and is occasionally seen in previously healthy people (Gorham, 1961; Barraclough and Braimbridge, 1967). The diagnosis of this condition can be difficult, and is frequently not made until necropsy. Uhland and Goldberg (1964) and Coon and Coller (1959) showed that in two necropsy series of fatal pulmonary embolism only 9% and 12.9% were correctly diagnosed during life. The symptoms and signs of pulmonary embolism have been fully described by Gorham (1961) and by Sevitt and Gallagher (1961). Small emboli can occur with few symptoms and without abnormal physical signs. Their passage often heralds the release of larger and perhaps fatal emboli a few hours or days later.

The electrocardiogram is helpful only when a large proportion of the pulmonary circulation has been obstructed. In the majority of patients with small emboli it remains unchanged.

The radiological signs of acute pulmonary embolism include enlargement of the pulmonary arteries and of the right side of the heart, the abrupt termination of one or more branches of the pulmonary arteries, and oligaemia of the lung fields. However, these signs are seen in only 30–50% of patients shortly after the embolus (Williams and Wilcox, 1963; U.C.L.A. Interdepartmental Conference, 1967). Elevation of one or both hemidiaphragms, small areas of collapse, or patches of infarction may develop later (Stein *et al.*, 1959). Pulmonary angiography is the most reliable way of demonstrating the position of pulmonary emboli, but it is not without risk (Sabiston *et al.*, 1965; Goodwin, 1965). It can be deceptive (Marable *et al.*, 1966) and may fail to show small peripheral emboli (Sasahara *et al.*, 1964; U.C.L.A. Interdepartmental Conference, 1967).

It is clear from a perusal of the literature on lung scanning (Wagner *et al.*, 1964b; Hatch *et al.*, 1965; Friedman and Braunwald, 1966; Lopez-Majano *et al.*, 1966; Quinn and Head, 1966; Jones *et al.*, 1967; Mishkin and Wagner, 1967; Tauxe *et al.*, 1967) and from other patients in this series that almost all pulmonary disease, several cardiac conditions, and some upper abdominal afflictions, such as subphrenic abscess, can disturb pulmonary perfusion. An individual lung scan is never diagnostic of the underlying disease, though it can often be highly suggestive of pulmonary embolism. Pulmonary angiography was not performed with any frequency in this series, and further confirmation of the presence of emboli was rarely obtained.

In a patient suspected of having a pulmonary embolus a normal chest radiograph and an abnormal lung scan, with several areas of diminished perfusion, make the diagnosis almost certain. There are exceptions. Patients with bronchial asthma or with chronic bronchitis and emphysema without evidence of pulmonary embolism have uneven pulmonary perfusion, and sometimes their lung scans closely resemble those seen in pulmonary embolism. When the chest radiograph shows signs suggesting pulmonary embolism the lung scan usually demonstrates larger and more numerous defects in perfusion than were suspected. If both the chest radiograph and the lung scan are normal the diagnosis becomes highly improbable.

Between 20 and 50% of patients suffering from massive pulmonary embolism survive more than two hours, only to die a few hours or days later (Gorham, 1961; Stoney *et al.*, 1963). With the advent of cardiopulmonary bypass pulmonary embolectomy is being used with increasing success, not only as an emergency procedure (Cooley *et al.*, 1961; Sharp, 1962; Makey and Bliss, 1966; Barraclough and Braimbridge, 1967) but also as an elective procedure when an embolus fails to resolve (Lord Brock *et al.*, 1967). If a preparation of ^{99m}Tc-MAA or ^{131}I-MAA is available lung scanning offers a safe and rapid assessment of pulmonary perfusion in patients who have collapsed and who may have had a massive pulmonary embolus. An anterior lung scan with ^{99m}Tc-MAA can be completed in less than 15 minutes.

If the lung scan demonstrates large defects in pulmonary perfusion and pulmonary embolectomy is considered then pulmonary angiography should be carried out to show the size and position of the emboli.

If anticoagulant or thrombolytic treatment is undertaken repeated lung scanning can demonstrate the restoration of pulmonary blood flow without resorting to repeated pulmonary angiography (Sautter *et al.*, 1964; Shibata *et al.*, 1966; Poe *et al.*, 1967; Tow and Wagner, 1967). In the present series complete restoration of pulmonary blood flow as shown by a normal lung scan has not been seen in less than eight days. Most defects in perfusion due to pulmonary emboli seem to take three or four weeks to resolve, though multiple small defects have persisted for as long as seven months. The appearance of new defects in perfusion in patients on anticoagulant therapy, with no new symptoms, has been observed on several occasions, suggesting the failure of anticoagulant therapy to prevent further embolization and the need for further measures such as inferior vena caval plication.

Summary

Lung scanning with technetium-^{99m}-labelled macroaggregated human serum albumin has been carried out on more than 200 occasions without any complications.

In patients suspected of having pulmonary embolism the lung scan supported the diagnosis in 50%, excluded it in 22%, was unhelpful in 18%, and suggested the presence of pulmonary hypertension in 10%. Repeated lung scanning has demonstrated a variable degree of restoration of pulmonary perfusion after pulmonary embolism, and may be used to assess the effectiveness of anticoagulant or thrombolytic therapy.

It is a pleasure to record my thanks to the many physicians and surgeons who have referred patients for lung scanning. In parparticular Professor Sir Max Rosenheim, Professor R. S. Pilcher, Dr. H. Nicholson, Dr. P. J. Heaf, Dr. E. J. Ross, Dr. A. Hollman, Dr. P. D. B. Davies, and Mr. J. L. Provan have given much encouragement throughout this work. I am grateful to Mrs. J. Lowe and Mr. F. Duck for the early preparations of ^{99m}Tc-MAA. Little of this work would have been possible without the untiring assistance of Miss J. Jackson, who has prepared many batches of ^{99m}Tc-MAA and has also assisted with the scanning procedures. The photographs were kindly prepared by the Medical School Photographic Department.

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