^{133}Xe VENTILATION SCANNING IMMEDIATELY FOLLOWING THE ^{99m}Tc PERFUSION SCAN

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In performing combined ventilation-perfusion studies in the diagnosis of pulmonary emboli, there are several important advantages to be gained by doing the ventilation study immediately after the perfusion scan. Yet the scatter from ^{99m}Tc is relatively intense at the 81-keV photopeak of ^{133}Xe and the possibility exists that this scatter might substantially degrade the ventilation image. For this reason the ventilation study is often done either immediately before the perfusion scan or on the following day.

The ratio of ^{133}Xe ventilation counts to ^{99m}Tc background counts was calculated for 43 patients who underwent single-breath ventilation studies immediately after perfusion scanning. In addition, background subtraction procedures were performed by computer on data obtained from 21 of these patients. Unprocessed images were compared with those obtained after subtraction of the ^{99m}Tc background falling within the xenon window. Comparisons show that there is little or no image degradation due to the ^{99m}Tc scatter and that ventilation scanning can be performed immediately after the perfusion scan with a negligible loss of diagnostic information.

Pulmonary embolism is a common disease. Early diagnosis is often difficult partly because of the nonspecific nature of patient complaints and physical findings but also because of the lack of a simple and practical specific diagnostic procedure. Early hopes that pulmonary perfusion scanning might play this role have not been fulfilled. Although the perfusion scan has proven to be very helpful in many cases, its value has been limited by its lack of specificity. Unfortunately, primary perfusion abnormalities due to vascular obstruction often cannot be distinguished from perfusion deficits secondary to either parenchymal destruction or primary abnormalities of ventilation (*1*).

By mid-1970, it had been shown that ventilation scanning could successfully differentiate between emboli without infarction and most other causes of decreased perfusion (*2–4*), except perhaps in patients with widespread destructive lung disease. Combined ventilation-perfusion scanning then was able to achieve in many cases what perfusion scanning alone could not and a satisfactory test for the presence of emboli seemed to be within reach. Yet problems have arisen with combined scanning that have not been fully resolved and the procedure is not yet in general use. Xenon-133, the agent of choice for ventilation scanning, has a photopeak at 81 keV whereas ^{99m}Tc, the agent of choice for perfusion scanning, has its main photopeak at 140 keV. Because there is a substantial amount of scatter at 81 keV from the technetium (including the lead K x-ray emitted from the collimator), the ventilation study is generally performed first to prevent this unwanted signal from being received in the xenon window and to obviate the possibility of resultant ventilation image degradation. Yet for practical reasons including convenience, cost, and patient selection, it would be helpful if the ventilation study could be performed immediately after the perfusion scan rather than before it.

The purpose of this paper is to demonstrate that the single-breath ventilation study can in fact be performed immediately after the perfusion scan without significant degradation of the ventilation image.

MATERIALS AND METHODS

Forty-three ventilation studies in patients with suspected pulmonary emboli were performed on a

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Searle Radiographics Pho/Gamma HP scintillation camera and were recorded on videotape. The last 21 studies were recorded on separate tapes and retained permanently. These were later replayed into a Searle Radiographics Clincom computer and area-of-interest and background subtraction procedures were performed.

For administration and collection of the radioactive gas the patient was connected to a 13.5-liter oxygen-filled spirometer through a closed circuit system of tubing and valves with a CO_2 absorber in the inspired air line. At the completion of the study the proper adjustment of two T-shaped stopcocks allowed the spirometer to be bypassed and a system of one-way valves permitted the inspiration of room air while expired air was directed into a collection bag.

In all patients perfusion scans were performed first with 3 mCi of ^{99m}Tc-human albumin microspheres (3M Company) injected intravenously with the patient supine. Most were done on a standard 5-in. dual-probe scanner but a few were performed on the scintillation camera. Four views were obtained whenever possible. Ventilation studies were performed immediately after the perfusion scan with 20 mCi of ^{133}Xe in air injected into the inspired air stream.

Patients were chosen to undergo a ventilation study if a definite abnormality was present on one or more views of the perfusion scan. For the ventilation study that view was chosen in which the perfusion abnormalities showed to best advantage and one of four standard collimators was selected depending on the needs of the individual study. The patient was then positioned accordingly in front of the scintillation camera. To minimize patient movement during the procedure, patients were always studied supine unless there was a specific contraindication such as severe orthopnea.

A 250,000-count perfusion image was obtained first for later comparison with the ventilation image. The camera pulse-height analyzer was reset for the 81-keV ^{133}Xe photopeak (using a 20% window) and a 100,000-count scintiphoto and simultaneous videotape recording of the ^{99m}Tc background scatter were obtained. The patient, still in the same position, was then connected to the oxygen-filled spirometer and after breathing oxygen quietly for about a minute was instructed to exhale maximally, take a full inspiration, and hold his breath as long as possible. The xenon was injected at the mouthpiece during the vital capacity inspiration with care being taken to administer the whole dose by the end of inspiration so that the entire 20 mCi would be in the lungs during the subsequent breathhold. Data were recorded until motion of the spirometer signaled the end of breathholding. The T-shaped stopcocks were then adjusted appropriately and the radioxenon was washed from the lungs into the collection bag. Counting rates for the ^{99m}Tc scatter in the xenon window and for the ventilation study were then obtained from the videotape. Images were obtained either directly from the tape or after processing by the computer.

RESULTS

In order to quantitate the contribution of the ^{99m}Tc scatter to the final ventilation image, the ratio of the ^{133}Xe ventilation counts to the ^{99m}Tc background counts (Xe:Tc ratio) was calculated for each patient. The total counts obtained during the ventilation study were measured first (from the videotape) and the time required for the study noted. The number of ^{99m}Tc scatter counts for this same time period was then obtained from the tape and subtracted from the total counts to give the number of counts due to ^{133}Xe alone. The Xe:Tc ratio was obtained by dividing this value by the counts due to the ^{99m}Tc scatter. In effect, this ratio is a signal-to-noise ratio with the ^{133}Xe counts corresponding to the signal and the ^{99m}Tc scatter counts corresponding to the noise.

A total of 43 patients were studied with an average Xe:Tc ratio of 9.0 and a range of 3.5–15.3. The final 21 patients were recorded on videotape and all further results are derived from this subgroup. Their Xe:Tc ratios were essentially the same as for the group as a whole (average ratio 9.3).

Since the ventilation studies necessarily included a variable amount of ^{99m}Tc scatter degrading the final image, it became important to determine how much the scatter affected the quality and interpretability of that image. To do so required a comparison of the ventilation image with scatter present with an image obtained at the same time and under the same circumstances but without the ^{99m}Tc background. The easiest way to obtain the latter was by point-by-point subtraction of background from the former and this was done on the computer using a 64 $\times$ 64 matrix. When unprocessed scintiphotos (i.e., Xe plus Tc) were compared with scintiphotos obtained after background subtraction (i.e., Xe only), no major differences could be found in any of our 21 patients. Minor differences primarily representing counts outside the lung fields were evident in some cases and were most prominent in patients with low Xe:Tc ratios. But in no case did the overall quality and interpretability of the images differ significantly. Figure 1 shows unprocessed and post-subtraction views on the four patients with the lowest Xe:Tc ratio.

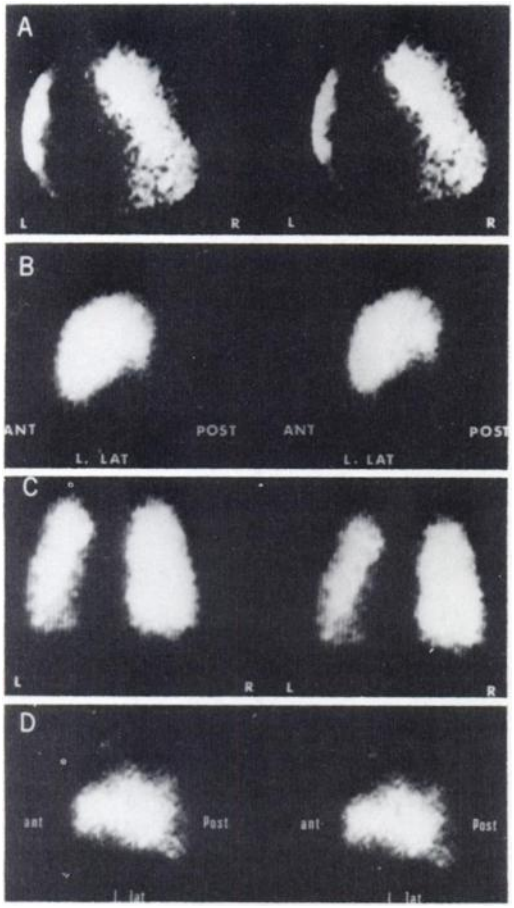

FIG. 1. Single-breath ventilation studies in four patients with the lowest Xe:Tc ratios. Comparison of unprocessed images (left) and images after subtraction of ^{99m}Tc background (right). (A) Patient FS, right lung, posterior view. Xe:Tc ratio, 3.5. (B) Patient HF, left lateral view. Xe:Tc ratio, 5.2. (C) Patient RM, posterior view. Xe:Tc ratio, 5.9. (D) Patient AA, left lateral view. Xe:Tc ratio, 6.8.

At low Xe:Tc ratios it might be expected that the ^{99m}Tc scatter would contribute enough to the final image to degrade it more than Fig. 1 demonstrates. There are two major reasons why this is not so. In the first place, imaging of the scatter falling in the region of the xenon photopeak (81 keV) shows a badly degraded image of the distribution of perfusion. "Hot" and "cold" areas tend to blend together to form a more or less uniform level of activity over the area of the lung (Fig. 2). Thus the scatter background acts as a kind of fog in the final ventilation image adding counts relatively uniformly over the entire lung area. Second, the Xe:Tc ratios described above were calculated over the entire surface of the crystal. The ratios over lung alone would be more relevant and somewhat higher since the scatter is distributed over the whole crystal (Fig. 2) whereas the counts from the ^{133}Xe are essentially confined to the lung fields. These latter ratios were estimated by using areas of interest over lung and the results for the four patients in our study with the lowest Xe:Tc ratios are shown in Table 1. There is a minimum "effective Xe:Tc ratio" of 5.6. A ratio of this magnitude is compatible with a relatively small amount of image degradation from the background as shown in Fig. 1.

DISCUSSION

There are four reasons why the ventilation study should be performed after the perfusion scan.

Patient selection. In the diagnosis of pulmonary embolism only those patients with perfusion deficits consistent with emboli require a ventilation study for further evaluation. Many patients either have normal perfusion or localized abnormalities explainable by infiltration seen on x-ray. A ventilation study serves no purpose in these patients but can be avoided only if the perfusion scan is done first.

Choice of view. When the ventilation study is done first, the posterior view is usually obtained as it is the single view most likely to give the needed information. But when perfusion abnormalities are more clearly outlined on an anterior or lateral view, that particular view would be most appropriate for the ventilation study. Most effective choice of view then requires the perfusion scan to be done first.

Choice of collimator. If the ventilation study is done first, a diverging collimator is necessary so that both lungs can be included in the field of view. But when a prior perfusion scan has been performed, collimator selection can be based on the requirements of an individual case. For example, when per-

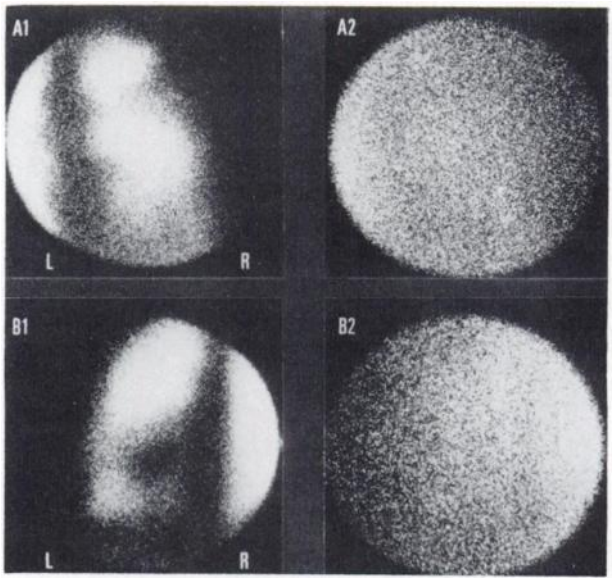

FIG. 2. Perfusion images (left) and corresponding scatter images (right) were obtained few seconds apart by lowering window on Anger camera from ^{99m}Tc photopeak (140 keV) to ^{133}Xe photopeak (81 keV) with patient position constant. Two hundred fifty thousand counts were obtained in all cases. Several small perfusion defects (A_1) and single large defect (B_1) are shown to become virtually undetectable when scatter at 81 keV is imaged (A_2 and B_2).

TABLE 1. Xe:Tc RATIOS OVER WHOLE CRYSTAL AND OVER LUNG AREA ONLY

Patient	Xe:Tc (crystal)	Xe:Tc (lung only)
FS	3.5	5.6
HF	5.2	7.2
RM	5.9	7.8
AA	6.8	9.0

fusion defects are fairly localized or when a lateral view is chosen, a high-resolution collimator may permit better image definition or a high-sensitivity collimator may be helpful in a patient whose breath-holding capacity is likely to be limited.

Easier positioning. In performing the ventilation study the technologist first must estimate where the lungs are. To be certain of including both lungs in the field of view of the diverging collimator he must back the collimator away from the patient but resolution will decrease with distance. If he keeps the collimator close, he runs the risk of cutting off the apices, the bases, or both. This problem is obviated by performing the perfusion scan first since the patient can be positioned on the basis of the distribution of the ^{99m}Tc present in his lungs.

For these reasons the perfusion scan should be performed first. One possible approach is to do the ventilation study the following day after the ^{99m}Tc has decayed to low levels. Unfortunately this would introduce several new objections:

1. Delayed interpretation of results when early diagnosis and treatment may be a necessity.
2. A 24-hr interval between procedures that ideally should be performed at the same time since evolution of the underlying disease can occur rapidly (as in emboli or asthma).
3. Inconvenience for the patient who has to make an extra trip to the department. For an in-patient it may interfere with other scheduled tests and lengthen the hospital stay.
4. Inconvenience for the department where scheduling difficulties and delays due to waiting for a late patient are compounded by a second separate visit and paperwork is increased.

It seems clear then that the ideal approach would be to perform the ^{133}Xe ventilation study immediately after the ^{99m}Tc perfusion scan. The data presented demonstrate that this is in fact feasible with a negligible loss of diagnostic information.

It should be pointed out that the results described are only valid for a single-breath ventilation study. Often additional information is required and further studies may be necessary such as equilibrium and/or washout studies. Valid images at equilibrium could be obtained with our method by increasing the dose of ^{133}Xe enough to offset both the dilution throughout the closed spirometer system and the loss through the lung capillaries into the blood. Preliminary studies suggest that this would only require an extra 5–10 mCi provided that the volume within the spirometer was kept to a minimum (unpublished data). Washout studies, however, would generally require much larger doses unless a computer was available to subtract the ^{99m}Tc background.

Fortunately, the diagnosis of pulmonary emboli does not require the addition of these further studies. In pulmonary embolism without infarction there is abnormal perfusion associated with normal or nearly normal ventilation (*5,6*). In most other lung diseases, abnormalities of perfusion are associated with similar abnormalities of ventilation (*7*). The single-breath image accurately depicts the distribution of ventilation and is therefore useful in differentiating the normal ventilatory pattern seen with emboli from the abnormal pattern seen in most other lung diseases.

Although the use of a computer was necessary to validate this technique, in the clinical situation only a spirometer and a scintillation camera are required. The entire procedure takes about 20 min and has been for us a simple and useful aid in the differentiation of emboli from other forms of lung disease.

This study demonstrates by the use of a computer that single-breath ventilation imaging can in fact be performed immediately after the perfusion scan. This allows the selection of patients for the ventilation study to be based on the results of the perfusion scan and hence permits the exclusion of many patients from an unnecessary procedure. In addition, the appropriate view and collimator for the ventilation study can be chosen on the basis of information derived from the perfusion scan, and the advantages of immediate diagnosis, easy positioning, and nearly simultaneous study of ventilation and perfusion can also be realized.

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