Comparison of Quantitative Ventilation–Perfusion Lung Scan Results Using Different Xenon-133 Ventilation Images

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Objective: This paper evaluates the influence of the specific ^{133}Xe ventilation images used to calculate differential function in quantitative ventilation-perfusion lung scans.
Methods: Whole-lung differentials were determined on 43 ^{133}Xe ventilation/^{99m}Tc-macroaggregated albumin perfusion studies. Ventilation calculations were performed for the first-breath, up to three equilibrium and the composite of all equilibrium images, and perfusion calculations were performed for the anterior and posterior images and their geometric mean. Differences of $\geq 5\%$ between comparable images were considered significant.
Results: The first-breath ventilation differential differed from at least one equilibrium view in 13 patients (30%) and from the composite of all equilibrium images in seven patients (16%), while the posterior perfusion differential differed from the anterior differential in 15 patients (35%) and from the geometric mean differential in six patients (14%). By comparison, the posterior or geometric mean perfusion differential differed from either the first-breath or composite ventilation differential in 31 patients (72%). Nine patients (21%) had ventilation/perfusion discrepancies $\geq 10\%$, with ventilation differentials more symmetric in seven patients.
Conclusion: The choice of ^{133}Xe ventilation image has only a limited effect on differential calculations. Discrepancies are more frequent between ventilation and perfusion differentials, making it important to determine both, particularly in patients with asymmetric lung disease.
Key Words: quantitative ventilation/perfusion imaging; xenon-133; technetium-99m-MAA; differential lung function

Quantitative radionuclide ventilation/perfusion lung scans are widely used for assessing high risk patients prior to lung resection (*1–7*). The relative contribution to total pulmonary function by the lung being considered for surgery is often used to judge whether a patient would tolerate a lobectomy or pneumonectomy. Quantitation is most often derived from perfusion studies, which require little patient cooperation, are technically easy to perform and yield accurate and reproducible results. Ventilation quantitation is more directly related to the physiological measures of lung function obtained in pulmonary function tests, but results may depend upon the radiopharmaceutical used (gas versus aerosol) and the adequacy of patient cooperation and effort.

The technical aspects of the determination of differential lung ventilation and perfusion, although studied by several investigators (*8,9*), have received much less attention than the results of preoperative quantitation of perfusion alone (*10–15*), ventilation alone (*16*), or both perfusion and ventilation (*1–6,17*), for prediction of post-operative lung function such as FEV-1. The present study was performed to examine the influence of the selection of ventilation images on the results of quantitative radioxenon lung scans. Lung differentials, using different individual ventilation images or a combination of images, were determined and compared with each other and perfusion differentials were calculated by several methods. Factors influencing agreement and disagreement between the various differentials were then considered.

METHODS

Eighty consecutive quantitative ventilation/perfusion scans performed over a 6-yr period were reviewed. Twenty-one studies were excluded because study records were incomplete or original images could not be retrieved. An additional 16 studies were subsequently deleted because either a minimum of one first-breath and two equilibrium ventilation images were not obtained, or posterior oblique views were included which interfered with reprocessing as described below. The remaining 43 studies were recalled from archival tape storage for reanalysis and form the basis for this report.

Imaging Parameters

All studies were acquired on a large field-of-view gamma camera using an all-purpose, parallel-hole collimator. The camera has 91 photomultiplier tubes and a 3/8-inch thick NaI(Tl) crystal. The images were saved digitally in a 128 × 128 word format.

Ventilation images were obtained first in the posterior projection using 8–40 mCi of ^{133}Xe. A 150,000-count first-breath image during maximal inspiration was followed by two to four 30-sec equilibrium images. Washout images were then obtained at 30-sec intervals for approximately 5 min.

Following completion of ventilation imaging, 5 mCi (±10%) of ^{99m}Tc macroaggregated albumin (MAA) were administered intravenously and perfusion images were obtained. Imaging was performed in the posterior, anterior, left and right posterior oblique, left and right anterior oblique, and left and right lateral projections. For the purpose of this review, however, only the anterior and posterior projections were considered.

Analysis

For the ventilation study, whole-lung regions of interest (ROIs) were drawn on the first-breath (FB) image, and the same ROIs were then applied to all subsequent equilibrium views. The total counts in each region were tabulated for the first-breath, each equilibrium image (EQ1–EQ4), and a composite image (EQC) composed of a summation of either the first three equilibrium views (n = 33) or the two equilibrium images for those exams which only included these views (n = 10). For the perfusion portion of the study, whole lung ROIs were drawn on the anterior and posterior images. Geometric mean counts for each lung were then calculated. Lung differentials were calculated for all paired sets of ventilation and perfusion data, using the formula

$$\frac{\text{Counts (L or R)} \times 100\%}{\text{Counts L + Counts R}}.$$

Studies from all 43 patients were processed by a single, experienced nuclear medicine technologist. For the purpose of consistency, the differential values for the right lung were used for all comparisons. A difference of ≥5% between values of differential lung ventilation or perfusion was considered significant.

RESULTS

All patients were male, ranging in age from 40–80 yr (mean = 63 yr). The ranges of right lung ventilation differentials were as follows:

FB: 6.1–96.0%
EQ1: 10.5–95.4%
EQ2: 15.0–94.2%
EQ3: 22.6–93.6%
EQC: 16.6–94.4%.

Absolute differences between various ventilation differentials ranged from 0%–16.5%. Thirteen patients (30%) had at least one pair of ventilation differentials which disagreed by ≥5%, while four (10%) had at least one pair of ventilation differentials which disagreed by ≥10%. The frequency of disagreement between pairs of ventilation differentials is shown in Table 1. Disagreement between consecutive images was uncommon, as follows:

TABLE 1
Number of Instances of Disagreement Between Differential Lung Ventilation Calculations (43 Patients)

	EQ1	EQ2	EQ3*	EQC
FB	3 (7%)	6 (14%)	12 (36%)	7 (16%)
EQ1	X	1 (2%)	5 (15%)	2 (5%)
EQ2	X	X	1 (3%)	0
EQ3	X	X	X	2 (5%)

*n = 33
FB: First-breath; EQ1: First equilibrium; EQ2: Second equilibrium; EQ3: Third equilibrium; and EQC: Composite equilibrium (sum of EQ1–EQ3).

FB versus EQ1: 3 (7%)
EQ1 versus EQ2: 1 (2%)
EQ2 versus EQ3 (n = 33): 1 (3%).

However, the magnitude of disagreement with the first-breath image increased for later equilibrium views, the largest being in the 12 patients (36%) who had discordant first-breath and third equilibrium images. The disagreement between first-breath and third equilibrium images generally reflected the effect of the equilibrium phase on patients with significant obstructive airway disease (Fig. 1). Seven patients (16%) had disagreement between first-breath and composite images.

Whereas changes in the ventilation differentials reflected effects of physiologic movement of radioxenon, the differences among perfusion differentials represented only the influence of imaging a fixed distribution of ^{99m}Tc in the lungs from different projections. The anterior and posterior perfusion differentials differed by ≥5% in 15 of 43 patients (35%) (Table 2). Although the geometric mean of the anterior and posterior counts provides a more accurate estimate of the perfusion differential than either individual view, since the ventilation data all reflect posterior imaging, both posterior and geometric mean perfusion results were compared with the ventilation calculations.

Disagreement was considerably more frequent between ventilation and perfusion differentials than among either dataset alone. Using posterior perfusion results, more than 40% of patients had a ≥5% disagreement, while this discordance exceeded 50% using the geometric mean data (Table 3). Of 24 patients with disagreement between first-breath or composite ventilation and posterior perfusion, the absolute difference was ≥10% in nine, seven of whom had more symmetric ventilation. Patients with greater perfusion asymmetry tended to have more frequent disagreement with ventilation differentials; eight of nine (89%) with posterior perfusion differentials >70%/30% had at least one discordant ventilation/perfusion pair, compared with 23 of the remaining 34 patients (68%). In most cases, the largest ventilation/perfusion differences occurred in patients with better first-breath ventilation than perfusion in the lung with less perfusion, with trapping in that lung on washout images.
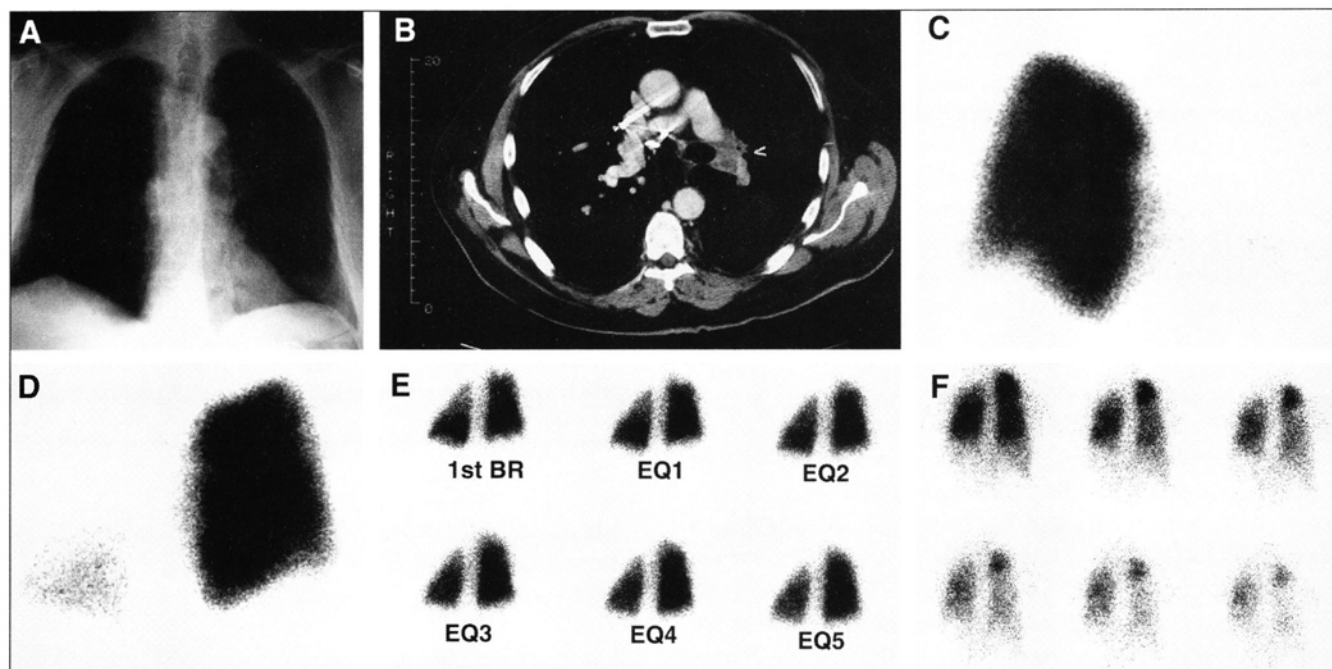
FIGURE 1. Patient with previous right upper lobe resection and new left hilar mass, seen on (A) CXR and (B, arrowhead) chest CT, has significant difference between appearance of perfusion ((C) anterior, (D) posterior) and ventilation ((E) first-breath and equilibrium and (F) washout) images. Left lung posterior perfusion differential is 13.1%, compared with first-breath and EQ3 ventilation differentials of 41.0% and 34.9%, respectively. These findings most likely reflect compromise of left lung blood supply secondary to central tumor, with relative preservation of regional ventilation. There is significant trapping in the left lower and right upper lobes on washout images due to airway disease.

DISCUSSION

Quantitative lung scanning is a noninvasive, readily available procedure that provides valuable prognostic information for predicting postoperative pulmonary function following surgical removal of a lobe or lung. Perfusion quantitation using ^{99m}Tc-MAA is technically simple and reliable, with the fixed distribution of activity in the lungs limiting variability due to image acquisition parameters and patient habitus (10–15). While use of radioaerosols has the potential for similarly simplifying the quantitation of ventilation, this technique does not provide the often important information concerning obstructive airway disease which is obtainable from the wash-out phase of a gas ventilation study. In addition, quantitation may be rendered less accurate by central airway deposition of aerosol in patients with poor pulmonary function, and the need to correct for residual ^{99m}Tc activity in a subsequently acquired perfusion scan may also be a problem. Radioxenon thus has certain advantages for quantitative ventilation imaging as reflected by its widespread use in published series (1,2,4–6,8,17). This investigation indicates that the details of image acquisition and processing have less effect on results than might have been expected.

Considering the first-breath and the composite equilibrium images as the most representative, ventilation differentials from these images differed by ≥5% in only seven patients (16%), and the mean difference for all 43 patients was 1.3%. All seven patients with discordant quantitative ventilation had increased right lung activity during equilibrium and variable amounts of trapping during washout, indicative of the effect of airway disease on the distribution of radioxenon on the first-breath view which was at least partially overcome during the period of equilibrium breathing. The maximum difference in the first-breath and composite right lung differentials for any patient was 10.6%, an amount likely to affect decisions regarding resectability in only the most marginal operative candidate.

Discrepancies between perfusion and ventilation differentials were observed in almost 75% of the patients studied, and in some instances the differences were sizable. In one patient, the differences between the first-breath ventilation and the posterior and geometric-mean perfusion differentials were 27.8% and 31.5%, respectively, reflecting significant ventilation to a lung which was hypoperfused secondary to external compression on hilar vascular structures (Fig. 1). Overall, ≥10% discrepancies between first-breath ventilation and posterior or geometric mean perfusion differentials were seen in eight and seven patients, respectively.

TABLE 2
Number of Instances of Disagreement Among Differential Lung Perfusion Calculations (43 Patients)

	Anterior	Geometric mean
Posterior	15 (35%)	6 (14%)
Geometric mean	5 (12%)	X

The present work demonstrates that xenon ventilation differentials can be calculated with equal confidence from first-breath, early equilibrium or composite equilibrium images. Although perfusion imaging is easier to perform and requires minimal patient cooperation, the common finding of disparities between the left/right differential perfusion and ventilation results demonstrates the need to acquire both datasets to obtain a complete understanding of relevant pulmonary physiology.

ACKNOWLEDGMENT

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