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^{81m}Kr gas and ^{99m}Tc-MAA V/Q ratio images for detection of V/Q mismatches*

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Abstract. Methods for creating ventilation/perfusion ratio images have been reported previously using radioxenon. With the availability of ^{81m}Kr gas, corresponding ventilation and perfusion views in multiple projections to evaluate for V/Q mismatch may be performed more readily. A technique for the creation of a functional V/Q ratio image to highlight V/Q mismatches to aid in the evaluation of pulmonary embolism is described. By removing nonpertinent and distracting information and by converting a 'cold spot' imaging modality to a 'hot spot' modality, these functional images aid in the synthesis of the information provided by the ventilation and perfusion images. The limitations due to technical artifacts and the advantages of using these functional images are described.

It is well established that the sensitivity of the perfusion lung scan is considerably higher than its specificity for the diagnosis of pulmonary embolic disease (McNeil 1976). However, it has been demonstrated repeatedly that the specificity is significantly enhanced by the addition of correlative ventilation images (McNeil 1976; Carter et al. 1982). Areas of V/Q mismatch, i.e., high V/Q ratios, may be due to tumor, radiation pneumonitis, tuberculous pneumonitis, or even pneumonia (Neumann et al., 1980). However, in the proper clinical setting and with a clear chest radiograph,

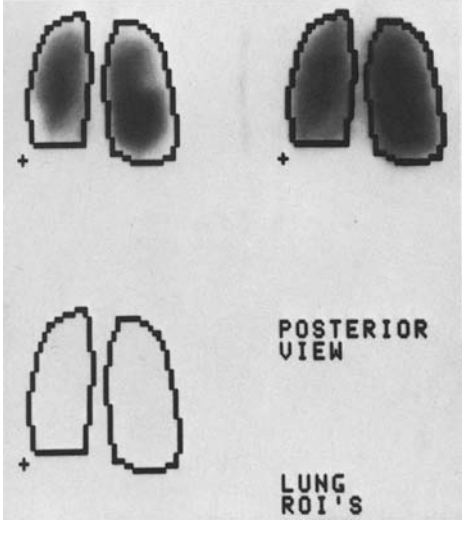

Fig. 1. A mask was created by using 'linked' cursors to manually draw a region of interest about the corresponding perfusion and ventilation images

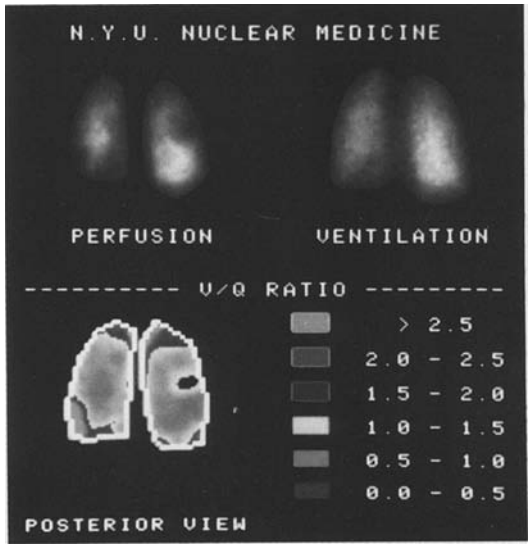

Fig. 2. The color scale was designed to permit easy differentiation between a 'normal' V/Q ratio (<1.5) and an abnormally elevated ratio

Table 1. Highlighted areas on V/Q ratio not identified as V/Q mismatch on raw images

Highlighted areas representing true V/Q mismatch	74
Highlighted areas corresponding to matched defects	8
Highlighted areas caused by artifact	28
Highlighted edge	18
Patient motion	2
Difference in intensity of raw V and Q images	6
Diffuse highlighting	2
Total number of highlighted areas not identified on raw images	110
Total number of anatomic areas represented	95

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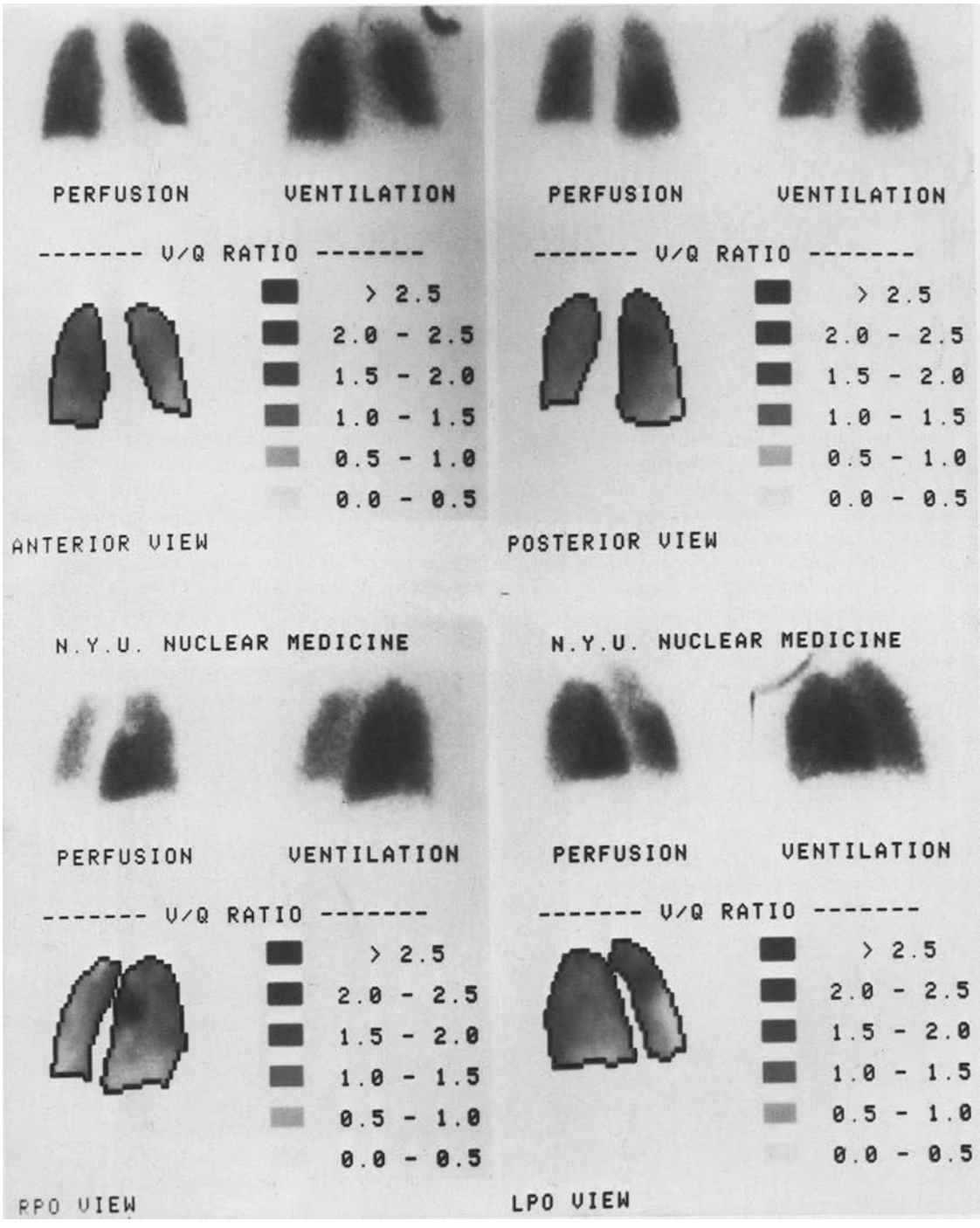

Fig. 3. The mismatched perfusion defect in the right lung demonstrated clearly on the right posterior oblique images is highlighted on the anterior, posterior, and LPO ratio images as well

V/Q mismatch may suggest the presence of pulmonary embolism (Li et al. 1978). While a V/Q ratio functional image will not increase the specificity of a ventilation-perfusion mismatch for the diagnosis of pulmonary embolism, this type of image can be a useful tool in the synthesis and interpretation of ventilation and perfusion studies.

Methods for the creation of V/Q ratios using ^{133}Xe (Burdine et al. 1972) or ^{127}Xe (Arnold and Wilson 1981) have been described previously. Quantitation of regional V/Q ratios using ^{81m}Kr have also been performed (Harf and Hughes 1978; Harf et al. 1978; Holmgren 1978). The purpose of this study was to develop and evaluate a method of creating V/Q ratio images from corresponding ^{99m}Tc-macroaggregated albumin (MAA) perfusion and ^{81m}Kr gas ventilation scans.

Materials and methods

Thirty consecutive patients referred for ventilation and perfusion scans to our Nuclear Medicine Department were

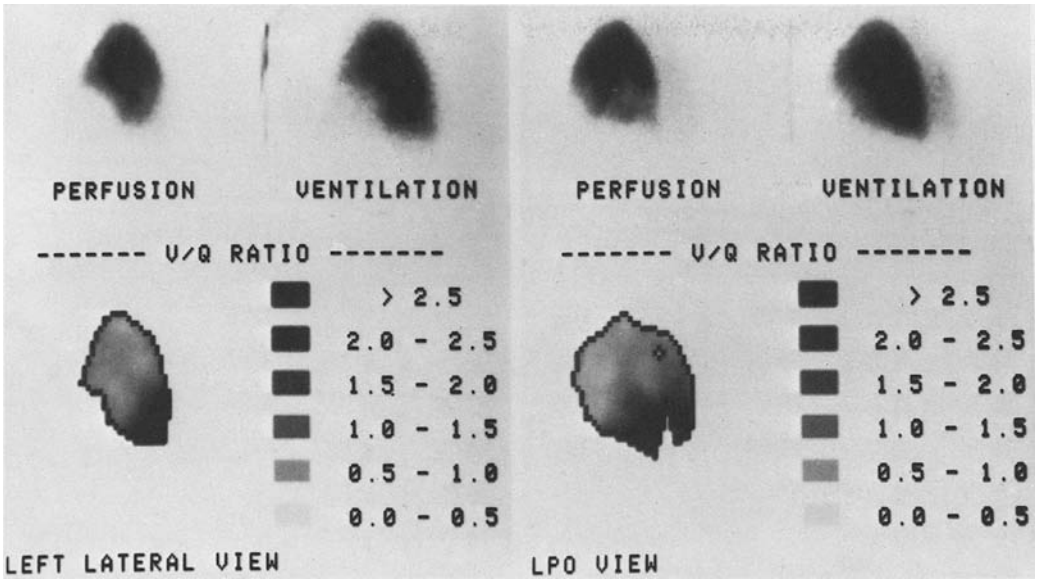

Fig. 4. The contour defect at the left base is clearly highlighted on the ratio image. Comparison with the LPO images confirms the presence of a mismatched defect in the posterobasal segment of the left lower lobe

included in this study. With the patient in the supine position, 3 mCi ^{99m}Tc-MAA was administered IV. Using an LFOV gamma camera equipped with a general all-purpose collimator, perfusion images were obtained in six standard views (anterior, posterior, right posterior oblique, left posterior oblique, and both laterals). The perfusion images were acquired with a 20% pulse height analyzer window centered on the 140-keV photon peak. After each perfusion image was acquired, a ventilation image was obtained without moving the patient. This was accomplished by the patient inhaling ^{81m}Kr gas via a mask. Ventilation images were obtained with a 20% window centered at 190 keV. Additional views were obtained in slightly different degrees of obliquity for clarfication when deemed necessary. All perfusion and ventilation images were obtained for 300,000 counts in a 64×64 digital acquisition matrix by a dedicated nuclear medicine computer. A chest X-ray performed within 12 h of the scans was obtained in each case.

Image processing was subsequently performed by a physician in an off-line fashion.

All images were first corrected for background activity by sampling the average count density in a manually drawn region-of-interest in the midline and just inferior to the lungs on anterior, posterior, and oblique views. On the lateral views, the ROI was placed posterior and just inferior to the lungs.

Corresponding pairs of ventilation and perfusion images were then normalized by scaling until the maximum pixel densities of the paired images were equivalent to one another. The images were then smoothed with a standard nine-point spatial filter.

Each pair of images was then 'masked' to exclude activity outside of the lungs from further analysis. This was accomplished by the operator in a manual, interactive fashion using 'linked' cursors. The technique involves the simultaneous, side-by-side display of the corresponding ventilation and perfusion images, each with a cursor superimposed upon it. These two cursors are 'linked' together under interactive joystick control. Moving in tandem, these cursors allow the creation of ROIs using information from both images simultaneously (Fig. 1). One ROI was manually drawn around the visualized lung activity of each lung; activity outside of these regions was automatically set to zero.

The V/Q ratio image was then created by dividing the smoothed, masked ventilation image by the perfusion image on a pixel-by-pixel basis.

Finally, the ratio image was scaled appropriately to highlight areas of abnormally high V/Q values (greater than 1.5) (Arnold and Wilson 1981). An appropriate color scale was created which provided emphasis of the abnormal regions and allowed differentiation from areas with normal V/Q ratio values (Fig. 2).

Raw images and the V/Q ratio images were interpreted separately by one of two nuclear medicine physicians. Readings of the two types of images were compared on a view by view basis.

Results

Table 1 summarizes the highlighted areas on the functional images not recognized as V/Q mismatches on the raw images.

One hundred and ten highlighted areas were identified which were not identified on the reading of the raw images as V/Q mismatches. These represented 95 separate anatomic segments or portions of segments. Of these, 74 represented true V/Q mismatches as verified by reevaluation of all six projections of the raw images.

The ratio images often highlighted V/Q mismatches on several projections when the defect was appreciated easily on only one projection of the unprocessed image. This emphasized the presence of the mismatch and heightened our ability to identify the existence of a mismatch and its anatomic location (Fig. 3).

When the raw perfusion image demonstrated only a contour defect, the ratio image called attention to the absence of perfusion and increased our confidence in identify-

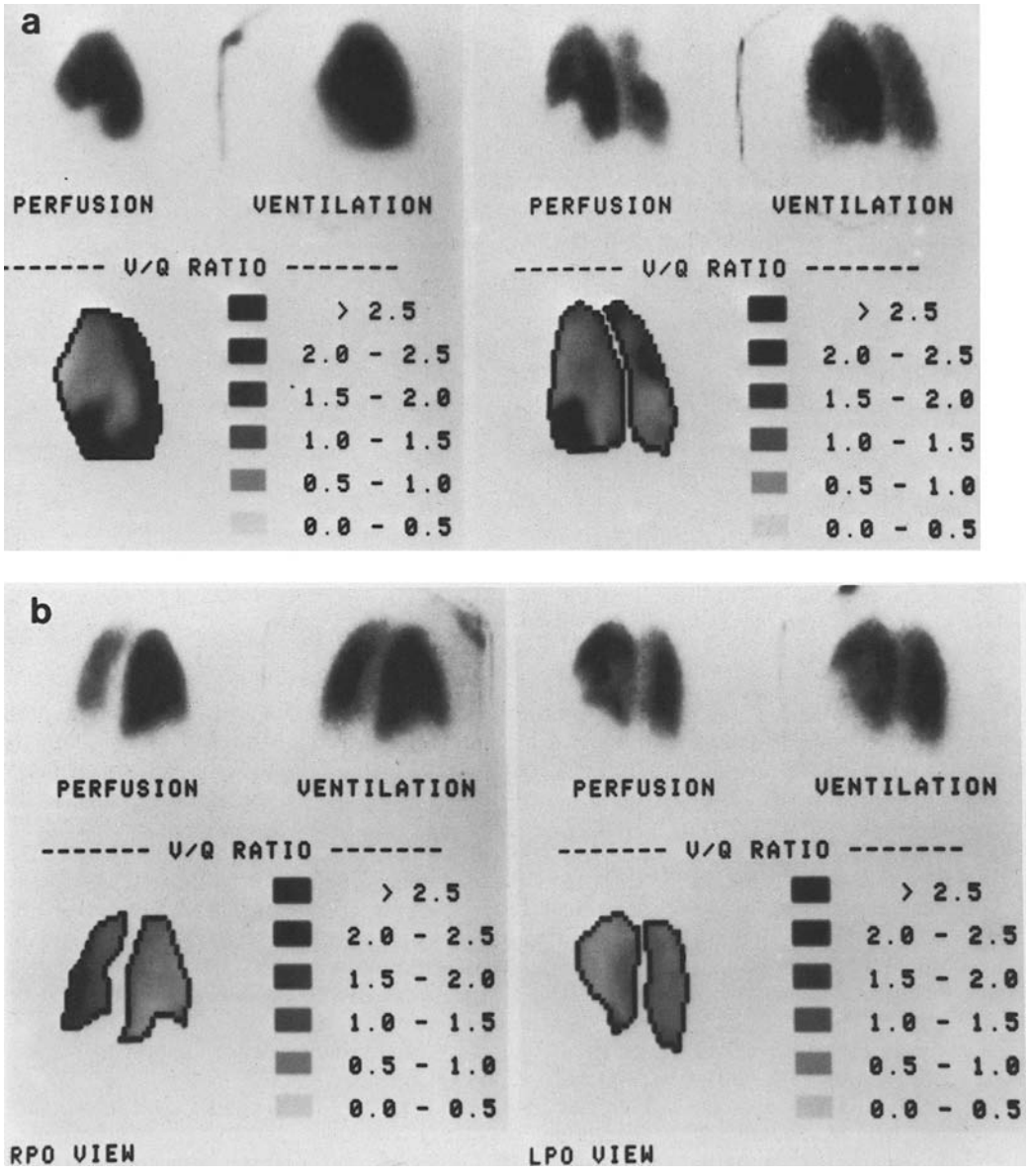

Fig. 5. a There is highlighting of the entire posterior border of the left lateral ratio image (*left*). The configuration of the highlighted area is suggestive of an artifact. Review of the LPO ratio image (*right*) confirms the absence of a mismatched defect in this location. **b** On the RPO view the ratio image incorrectly suggests the presence of a V/Q mismatch at the base of the left (distant) lung. However, the LPO projection clearly demonstrates the absence of a defect in this location

Table 2. Mismatches on raw images not highlighted on V/Q ratio images

Defects incorrectly identified as mismatches on raw images initially	4
Highlight not identified due to photographic error	1
Highlights with 1.0–1.5 value	4
Total number	9

ing a V/Q mismatch. This was particularly true at the apices of the lungs and at the periphery of the lung bases (Fig. 4).

Twenty-eight of the highlighted areas identified were due to artifact. Of these, 18 represented highlighted edges secondary to the larger size of the ventilation image as compared to the perfusion (Fig. 5a). A similar artifact has been described previously in studies using ^{127}Xe and is most likely due to the patient's deeper breathing during the ventilation portion of the study (Arnold and Wilson 1981). However, other factors such as problems with collimation of the higher energy photon of the ^{81m}Kr gas, and, perhaps, pulse pileup due to the superimposition of ^{99m}Tc-MAA activity on the ^{81m}Kr gas may affect the spatial resolution of the ^{81}Kr images.

Six of these highlighted areas occurred in the absence of any defect at all, but appeared to be due to the regional differences in intensity between the perfusion and ventilation image despite the usual method of scaling of the two images. This occurred most often in portions of the lung distant from the detector and in areas adjacent to the heart

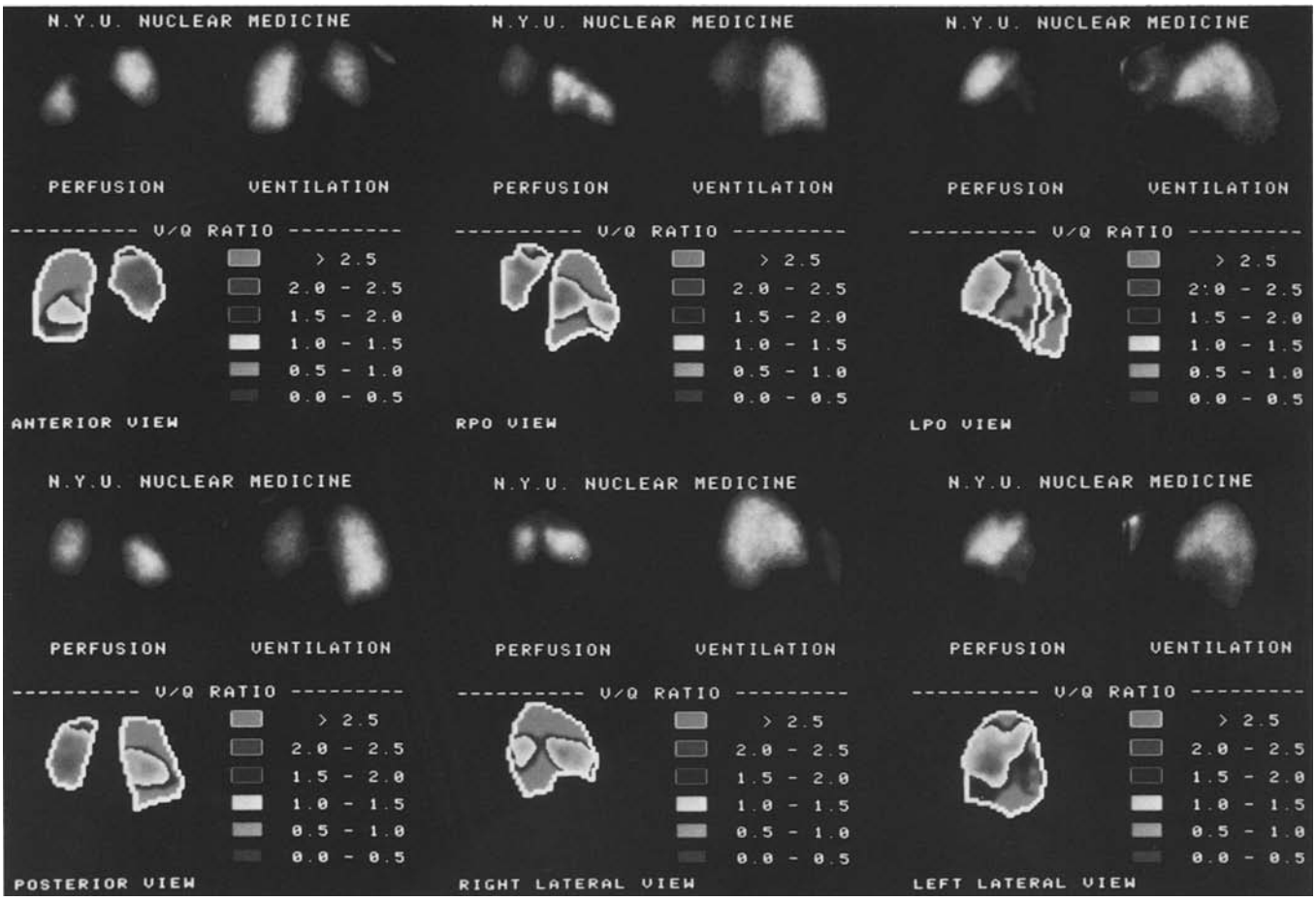

Fig. 6. Although the raw images plainly show the presence of ventilation-perfusion mismatches, the addition of the ratio images emphasizes the extensive nature of the mismatched defects

(Fig. 5b). The higher photon energy (190 keV) of the ^{81m}Kr gas compared with the 140 keV photon of the ^{99m}Tc-MAA results in greater photon penetration and less attenuation, giving rise to artificially high V/Q ratios.

Two of the incorrectly highlighted areas were due to slight changes in patient position between the performance of the perfsuion and the ventilation studies.

Two ratio images demonstrated diffuse high-lighting of the entire lung. These were felt to be due to technical problems in scaling the images.

Eight of these highlighted areas were interpreted on the raw images as matched defects. This incorrect highlighting of matching defects was caused by differences in the intensity of the activity of the raw ventilation images compared with the perfusion images; that is, while there were obviously corresponding defects on the ventilation and perfusion studies, the intensity of activity in the ventilation defect was higher than in the perfusion defect despite background subtraction. Many of the above technical factors including increased penetration and inadequate collimation may have contributed to the difficulty.

Mismatches found on the raw images but not highlighted on the functional images are summarized in Table 2.

From the initial reading of the raw ventilation and perfusion images, there were a total of nine areas which were felt to represent mismatches but which were not highlighted by the functional ratio images. Careful review of the raw images in these cases, revealed that four of these perfusion defects had been misinterpreted originally and were actually matched by ventilation defects. One mismatch identified on the raw images was not identified on the ratio image due to errors in photographic technique.

Four of these mismatches corresponded to areas on the ratio images with values of 1.0–1.5, just below the limit designated as normal. A value of 1.5 for the upper limit of normal has been used by other authors and has been clinically validated by them (Arnold and Wilson 1981).

Discussion

Krypton-81m gas has a short physical half-life (13.5 s), favorable energy characteristics (190 keV) for gamma camera imaging, particularly in the presence of ^{99m}Tc, relatively favorable dosimetry, and is easily administered (Goris et al. 1977; Schor et al. 1978). These advantages permit the acquisition of paired ventilation and perfusion images in multiple projections and facilitate a more accurate comparison of the distribution of regional perfusion and ventilation when compared with techniques using ^{133}Xe gas (Schor et al. 1979). In addition, the ^{81m}Kr study may be performed in patients who otherwise would be unable to cooperate for the more awkward ^{127}Xe or ^{133}Xe procedure (Goris et al. 1977) since the administration of ^{81m}Kr gas does not require a closed system and trapping mechanism and may be used

in patients requiring mechanical ventilation. However, the addition of the extra images increases the amount of data to be examined.

The V/Q functional image was designed to facilitate the synthesis of the increased numbers of images. Matching defects may be relevant to the patient's overall clinical problem; however, using the schema proposed by Biello et al. (1979) for the interpretation of ventilation and perfusion scans, matched V/Q defects in the presence of a clear chest radiograph are not contributory to the diagnosis of pulmonary embolism. Matching defects were not depicted on the functional image and in this way were removed from further consideration.

This technique emphasized an area of V/Q mismatch by converting a 'cold-spot' to a 'hot spot' on the image (Fig. 6) enabling more effective use of contrast enhancement (Sorenson 1980). In the evaluation of perfusion and ventilation scans for the diagnosis of pulmonary embolism, the most useful data is immediately brought to the interpreter's attention.

However, the incidence of falsely highlighted areas was not insignificant. Problems with highlighted edges caused by artifactually high V/Q ratios along the periphery of the lungs can be overcome largely by masking. The use of a medium-energy collimator may reduce artifacts due to the greater photon penetration of the ^{81m}Kr gas.

A more serious weakness in the application of this technique was the existence of a few defects not highlighted by this method.

While the sensitivity for the detection of V/Q mismatches is increased by the addition of the functional image, the technique does not enhance the specificity of the ventilation perfusion scan for the diagnosis of pulmonary embolism.

Nevertheless, when used in conjunction with the raw perfusion and ventilation images, the V/A ratio image is a useful tool to confirm the presence of V/Q mismatches. If ^{81m}Kr gas is to remain a widely used agent for ventilation scanning, the addition of this type of functional image can be a valuable adjunct to the analysis of ventilation and perfusion lung scans.

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