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Tomography of regional ventilation and perfusion using krypton 81m in normal subjects and asthmatic patients

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ABSTRACT Single photon emission computed tomography, a rotating gamma camera, and continuous inhalation or infusion of krypton 81m (half life 13 seconds) were used to measure regional ventilation ($\dot{V}$), perfusion ($\dot{Q}$), and ventilation-perfusion ($\dot{V}/\dot{Q}$) ratios in five normal subjects in supine, prone, and lateral decubitus postures and in three asthmatic patients (supine posture only) before and after inhalation of 2.5 mg nebulised salbutamol. Vertical and horizontal gradients of $\dot{V}$, $\dot{Q}$, and $\dot{V}/\dot{Q}$ were examined at three levels in each lung in regions of 1.9 cm^3 size. In normal subjects $\dot{V}$ and $\dot{Q}$ increased along the axis of gravity in all postures and at all levels in the lung except for $\dot{V}$ in the prone position. Smaller horizontal gradients were found with an increase in $\dot{V}$ and $\dot{Q}$ from caudal to cranial—again except in the prone posture, where the gradient was slightly reversed. Constraint to outward motion of the ventral chest and abdominal wall is the most likely explanation for the different behaviour in the prone posture. In chronic asthma the vertical gradients of $\dot{V}$ and $\dot{V}/\dot{Q}$ were the reverse of normal, but the $\dot{Q}$ gradient was normal. Bronchodilator treatment did not affect the vertical or horizontal gradients significantly, but analysis of individual regions showed that, relatively, $\dot{V}/\dot{Q}$ worsened in 42% of them; this was associated in two thirds with an increase in fractional $\dot{Q}$. After inhalation of β agonist local vasodilatation may influence $\dot{V}/\dot{Q}$ ratios in some units more than bronchodilatation.

Three dimensional reconstruction of function in an organ where gravity plays a prominent role offers definite advantages over two dimensional mapping. With emission computed tomography either with single photons (SPECT)[1] or with positrons (PET)[2 3] ventilation ($\dot{V}$), perfusion ($\dot{Q}$), and $\dot{V}/\dot{Q}$ ratios can be obtained using appropriate radionuclides. Because of their special properties (monoenergetic γ ray emission in coincidence) precise attentuation corrections can be made only with positron emission tomography (PET).[4] PET machines, in general, offer a limited survey of the lung (at present a maximum of five transaxial cuts), and an online cyclotron is required. With SPECT and a rotating gamma camera the whole lung can be surveyed but the attenuation corrections are extremely complex and of doubtful accuracy, and have generally been omitted.[1]

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For imaging with SPECT and PET systems subjects are confined to the decubitus, usually supine, posture. There is a considerable corpus of knowledge about regional lung function in the erect posture[5] but relatively few studies have been carried out in decubitus postures.[6 7] Since people spend a considerable proportion of time lying down, regional lung function in decubitus postures (supine, prone, right and left lateral) is of interest.

In this study krypton 81m, continously inhaled or infused, was used to measure regional ventilation, perfusion, and $\dot{V}/\dot{Q}$ ratio throughout both lungs. Five normal subjects were studied in various decubitus postures. In addition, three asthmatic subjects were studied, in the supine posture only, before and after bronchodilator inhalation. The short half life (13 seconds), relative insolubility (blood:gas partition coefficient 0.046 at 37°), and 190 KeV γ energy of krypton 81m offer many advantages in terms of count rate, spatial resolution, low radiation dose, and ease of administration and disposal.[8–10]

Table 1 *Forced expired volume in one second (FEV_1), vital capacity (VC), and ear lobe oxygen saturation (Sao_2) in three asthmatic subjects before and after inhalation of 2.5 mg nebulised salbutamol (all volumes BTPS)*

Patient No	*FEV_1 (l)*		*VC (l)*		*Sao_2 (%)*	
	Before	*After*	*Before*	*After*	*Before*	*After*
1	1.55	2.03	2.2	2.83	96	94
2	1.45	1.68	3.4	3.48	95	92.7
3	1.5	1.6	2.2	2.3	95	94

Methods

SUBJECTS AND PROTOCOL

The postural study involved five normal non-smoking volunteers aged 25–47 years (four of them male). All were medical graduates, free from a history of respiratory disease, who gave informed consent to the study. In each of them measurements were made sequentially in any two of four decubitus postures (supine, prone, and right and left lateral). In addition, three patients with longstanding chronic bronchial asthma were studied in the supine position before and after inhalation of 2.5 mg nebulised salbutamol (β agonist). Spirometry was undertaken and arterial oxygen saturation (by ear oximetry) was measured before and after the tomographic measurements (table 1). Krypton 81m gas was added (at 1.0 l min^{-1}) to a standard oxygen mask worn by the subjects for the inhalation study. ^{81m}Kr dissolved in 5% dextrose was continuously infused into a right arm antecubital vein (at 10 ml/min) for the measurement of regional perfusion.[11] After waiting 60 seconds for a steady state to be established, the inhalation and infusion continued for a further 6.5–8.5 minutes while data were collected with a rotating gamma camera. Subjects breathed quietly throughout the scans. A fan beside the face dispersed the small amounts of exhaled radioactivity. To permit 360° camera rotation with an intravenous infusion in place, subjects placed their arms above their heads throughout the study. They took care to avoid movement during and between the scans.

TOMOGRAPHY

Data were acquired with an IGE 400T gamma camera with a high resolution collimator interfaced with an MDSA[2] computer. Sixty four frames of four to six seconds' duration were acquired during a 360° rotation. The average voxel (element of volume: 0.62 × 0.62 × 1.24 cm) count ranged from 500 to 2000 for the ventilation and perfusion scans. The raw data were reconstructed by means of filtration followed by back projection to give transaxial sections through the thorax (fig 1). Coronal and sagittal sections were

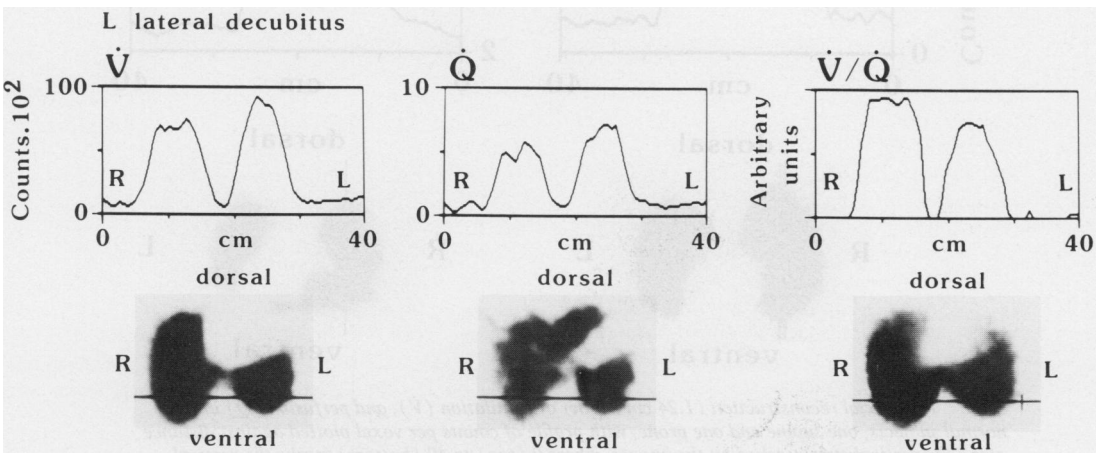

Fig 1 *Transaxial reconstruction (1.24 cm depth) of ventilation ($\dot{V}$), perfusion ($\dot{Q}$), and ventilation-perfusion ($\dot{V}/\dot{Q}$) ratio in a normal subject in the left lateral decubitus posture with profile of counts per voxel plotted against distance along a vertical strip from the right lung to the left lung at the level of the heart (16 cm from lung apex). Note the presence of the left heart (as negative image) in the left hemithorax and activity in the right heart on the $\dot{Q}$ image. $\dot{V}$ and $\dot{Q}$ are greater but $\dot{V}/\dot{Q}$ is less in the dependent lung.*

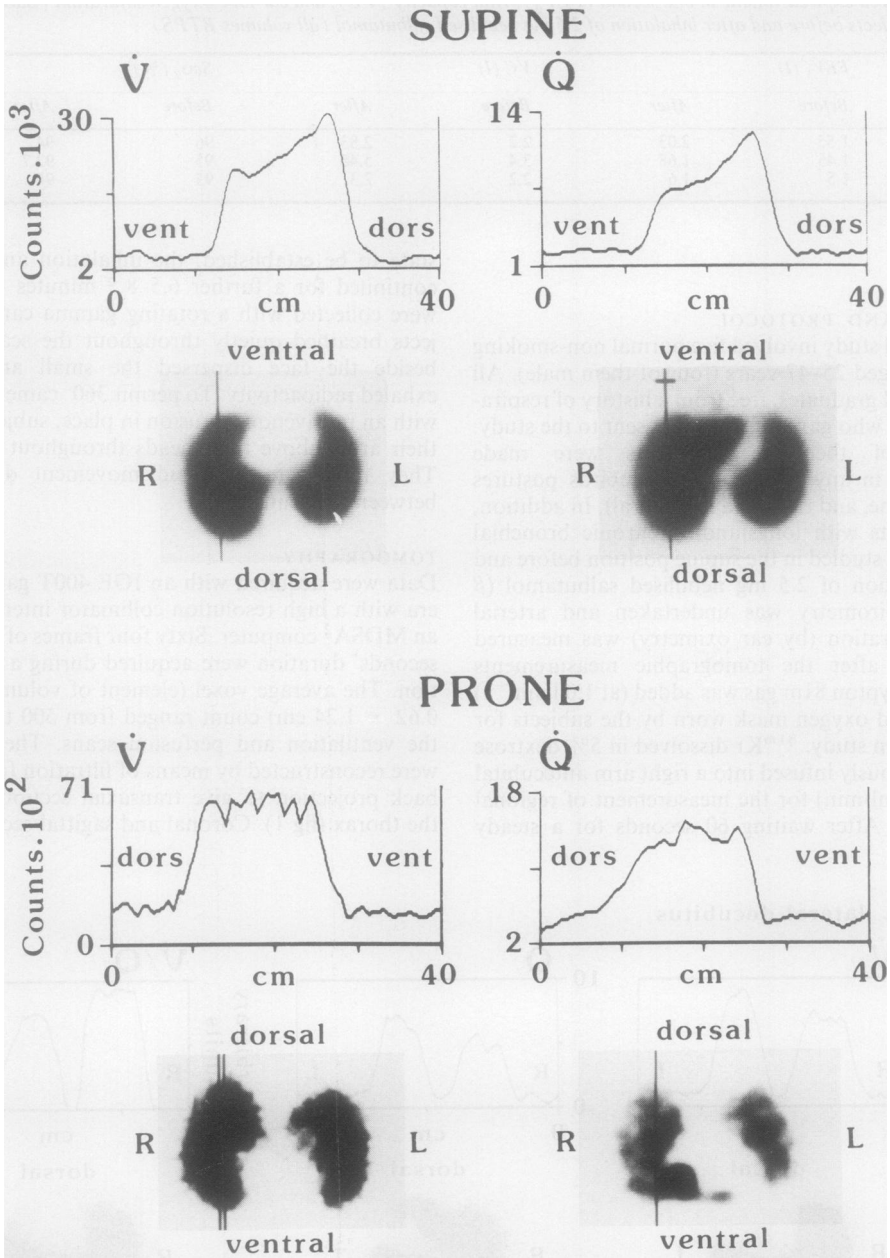

Fig 2 Transaxial reconstruction (1.24 cm depth) of ventilation ($\dot{V}$), and perfusion ($\dot{Q}$) in two normal subjects, one supine and one prone, with profile of counts per voxel plotted against distance along the vertical strip marked on the images, where 0 (top) to 40 (bottom) marks the vertical level in centimetres. Note in all cases except $\dot{V}$ (prone) ventilation and perfusion increase with increase of depth in the lung.

also examined. No attentuation corrections were made because of the complexity of the geometry within the thorax.

DATA ANALYSIS

Quantitative analysis was confined to transaxial lung slices two voxels (1.24 cm) thick. Peripheral regions—remote from central artefacts arising from infused ^{81m}Kr in the right heart, superior vena cava, and pulmonary arteries—were chosen for analysis. In the transaxial plane profiles (1 voxel width) were constructed from the ventral to the dorsal aspect through the middle of each lung (figs 1 and 2). The profile width and position were stored in the computer memory so that identical profiles could be drawn on the $\dot{V}$ and $\dot{Q}$ images. From the strip ventral, middle, and dorsal regions of interest were chosen eight voxels (5 cm) apart. The region of interest volume was 4 × 2 × 1 voxels (2.48 × 1.24 × 0.62 cm = 1.9 cm^3). The counts per voxel were normalised to the average voxel count for the whole lung. After normalisation the $\dot{V}$ and $\dot{Q}$ values for each region of interest were divided to obtain the $\dot{V}/\dot{Q}$ ratio. Three of about 20 transaxial slices (Nos 4, 10, and 16) were analysed in this way. The distance between each analysed slice was 7.5 cm. From the regions of interest in these slices (in the supine posture, for example) three ventral-dorsal profiles (in a vertical axis) of three regions of interest each were calculated from cranial to caudal, and, with the same regions of interest, three cranial-caudal profiles (ventral, mid, dorsal) were derived in the horizontal axis. The vertical axis was dorsal-ventral in the prone posture. In the lateral decubitus postures the vertical gradient was calculated across the transaxial slice in the dorsal region only to avoid artefacts from the heart and great vessels (fig 1). One region of interest (1.9 cm^3) was analysed in each lung, 15 cm apart. Three slices, 7.5 cm apart, were examined from the cranial, middle and caudal parts of the lung. Thus vertical and horizontal gradients were calculated for the dorsal regions only.

The analysis in the asthmatic subjects was similar to that for normal subjects in the supine posture, except that the width of the vertical and horizontal strips was four instead of two voxels. In addition to the cranial, caudal, ventral, and dorsal regions of interest (4 × 4 × 2 voxels), $\dot{V}$, $\dot{Q}$, and $\dot{V}/\dot{Q}$ were calculated for each voxel (20 in each ventral-dorsal strip and 10 in each lung for the dorsal-dorsal strip—that is, 180 regions of interest (4 × 1 × 2 voxels, 1.9 cm^3) for each subject. Because patients left the examining table to inhale the nebulised salbutamol, special procedures were used to match up positions in the studies before and after inhalation. The trachea and left and right main bronchi were identified in the transaxial slices of the ventilation study and used as fixed points for subsequent matching of position.

Results

NORMAL SUBJECTS

The most striking finding in the postural study was the loss of the vertical ventilation profile in the prone compared with the supine posture (fig 2). Perfusion increased along the gravity axis—ventral to dorsal (supine) and dorsal to ventral (prone)—in both postures, but in general dorsal $\dot{V}$ exceeded ventral irrespective of position (fig 3). The vertical (fig 3) and horizontal (fig 4) gradients for $\dot{V}$ and $\dot{Q}$ are plotted in supine, prone, and right and left lateral decubitus postures. The mean values for the three transaxial slices (cranial, mid, caudal) have been used to construct the vertical gradients; there were no substantial changes at the different cranial-caudal levels (table 2). Similarly, the cranial-caudal gradients are averages from the ventral, middle, and dorsal regions of interest or, in the lateral decubitus posture, from the upper and lower regions of interest in each lung. We found no systematic differences in cranial-caudal gradient corresponding to the vertical level (table 2). By least mean squares a linear fit from three regions of interest in ventral-dorsal or cranial-caudal directions was

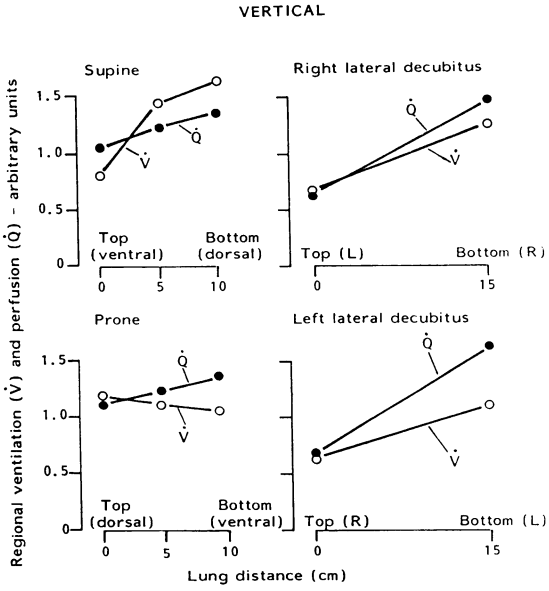

Fig 3 *Regional ventilation and perfusion plotted against lung distance in a vertical axis in normal subjects. Mean values for regions of interest from cranial, mid, and caudal transaxial slices from right and left lungs in supine and prone (n = 2) and from each lung in lateral decubitus (n = 3) postures. Note that $\dot{V}$ and $\dot{Q}$ increase in the direction of gravity except for $\dot{V}$ (prone).*

Table 2 *Percentage change of ROI* counts (normalised to average counts) per cm distance for ventilation ($\dot{V}$) and perfusion ($\dot{Q}$) in subjects A-D in supine and prone postures at different vertical (ventral-dorsal) and horizontal (cranial-caudal) levels*

Vertical (ventral-dorsal) gradients

	$\dot{V}$			$\dot{Q}$		
Supine	*Cranial*	*Mid*	*Caudal*	*Cranial*	*Mid*	*Caudal*
A	7.1	7.2	6.6	2.2	2.5	2.2
B	9.9	10	9.2	4.3	4.3	3.5
Prone						
C	−1.3	−1.7	−1.7	2.1	2.1	2.4
D	−1.1	−0.9	−1.4	3.3	3.5	3.7

Horizontal (cranial/caudal) gradients

	$\dot{V}$			$\dot{Q}$		
Supine	*Ventral*	*Mid*	*Dorsal*	*Ventral*	*Mid*	*Dorsal*
A	−0.4	0.6	−0.7	−1.2	−1.3	−1.1
B	−0.5	0.7	−1.0	−1.5	−1.9	−2.1
Prone						
C	1.8	1.8	2.1	0.9	1.1	0.7
D	2.4	2.4	2.6	0.7	0.5	0.4

*Region of interest.

Table 3 *Percentage change of ROI* counts per cm distance, as in table 2, for ventilation ($\dot{V}$) and perfusion ($\dot{Q}$) in five normal subjects (A-E) in right and left lateral decubitus postures at different vertical levels (cranial-caudal) and horizontally in dependent (bottom) and non-dependent (top) lung*

Vertical (ventral-dorsal) gradients

	$\dot{V}$			$\dot{Q}$		
R lateral	*Cranial*	*Mid*	*Caudal*	*Cranial*	*Mid*	*Caudal*
A	3.1	3.1	2.7	6.1	6.3	4.5
B	4.6	5.2	4.3	4.7	4.9	3.2
E	4.1	4.0	3.3	7.5	7.0	4.9
L lateral						
C	3.1	3.4	2.7	5.9	6.3	4.9
D	3.4	3.3	2.9	6.7	7.0	5.3
E	3.3	3.1	2.9	7.4	7.1	5.9

Horizontal (cranial/caudal) gradients

	$\dot{V}$		$\dot{Q}$	
R lateral	*Top (L)*	*Bottom (R)*	*Top (L)*	*Bottom (R)*
A	−0.8	−1.1	−1.5	−3.1
B	−1.1	−1.5	−1.5	−3.0
E	−1.1	−1.9	−2.1	−4.7
L lateral	*Top (R)*	*Bottom (L)*	*Top (R)*	*Bottom (L)*
C	−0.5	−0.9	−1.1	−2.1
D	−0.1	−0.9	−1.1	−2.5
E	−0.7	−1.1	−1.5	−3.0

*Region of interest.

obtained and lines to the ventilation and perfusion gradients were calculated, as percentage changes of counts per voxel per cm lung distance, for supine and prone (table 2) and lateral decubitus (table 3) postures. For a given posture there was comparatively little intersubject variation. Vertical gradients of ventilation are aligned along an axis determined by gravity, except in the prone posture. Perfusion increases from top to bottom in all postures. Horizontal gradients are generally smaller than vertical gradients, cranial $\dot{V}$ and $\dot{Q}$ values exceeding caudal values except in the prone posture. The largest horizontal gradients

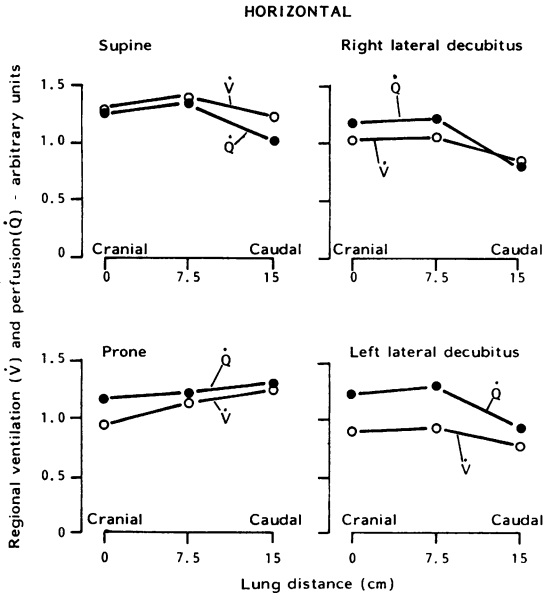

Fig 4 *Regional ventilation and perfusion plotted against lung distance in a horizontal axis in normal subjects in supine and prone (n = 2) and lateral decubitus (n = 3) postures. Mean values for ventral, mid and dorsal regions of interest from right and left lungs in supine and prone posture, but for dorsal regions of interest only in lateral decubitus posture.*

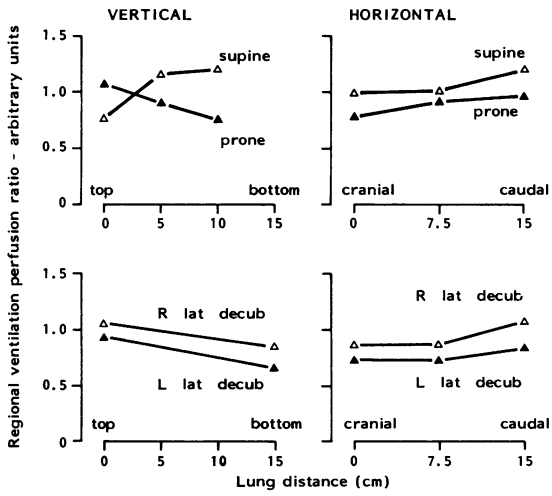

Fig 5 *Regional ventilation-perfusion ratio plotted against lung distance in normal subjects in supine and prone (n = 2) and lateral decubitus (n = 3) postures, calculated from the average of ventral, mid, and dorsal (horizontal gradients) or cranial, mid, and caudal (vertical gradients) (regions of interest from right (R) and left (L) lungs). The horizontal gradient in the decubitus posture is for dorsal regions only.*

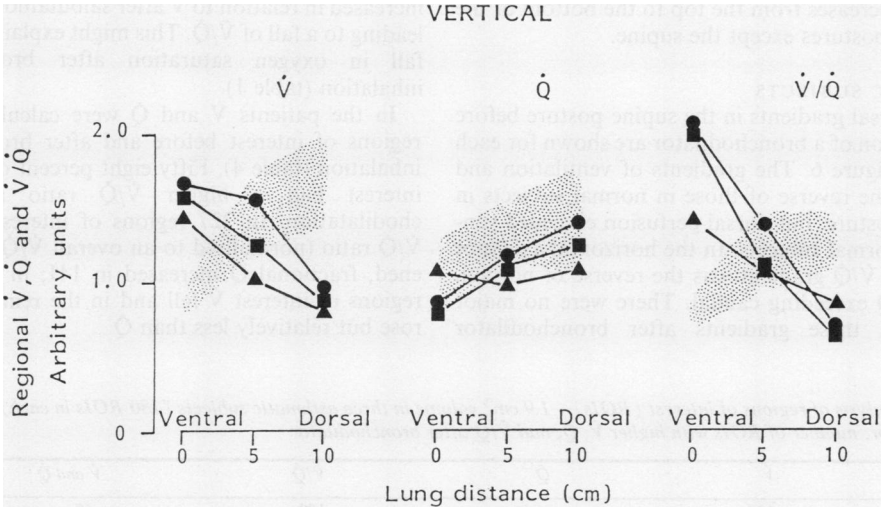

Fig 6 *Regional ventilation (V̇), perfusion (Q̇), and V̇/Q̇ plotted against lung distance in a vertical axis for three asthmatic subjects in the supine posture (● ▲ ■), taking mean of cranial, mid, and caudal regions of interest from the right and left lungs. The normal range is shaded.*

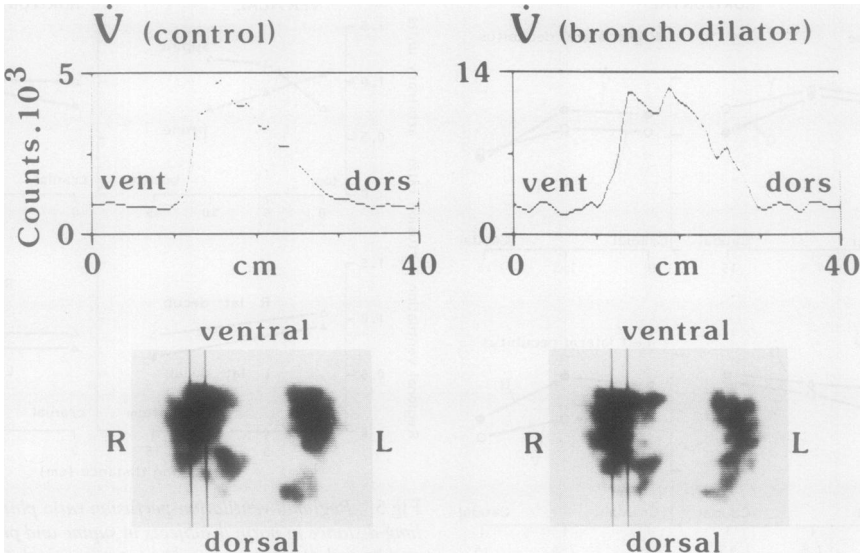

Fig 7 *Transaxial section (1.24 cm thick in mid lung (12.6 cm from lung apex)) of lung ventilation (V̇) imaged with krypton 81m inhalation in an asthmatic subject (No 1) in the supine posture before and after 2.5 mg nebulised salbutamol. Note in the profile of counts against distance the dorsal shift of V̇ after bronchodilator.*

were for V̇ in the prone posture (cranial < caudal) and for Q̇ in the dependent lung in lateral decubitus postures (caudal < cranial). V̇/Q̇ gradients in the vertical and horizontal axes are plotted in figure 5. There are no substantial cranial-caudal gradients, although caudal V̇/Q̇ tended to exceed cranial. In the vertical axis V̇/Q̇ decreases from the top to the bottom of the lung in all postures except the supine.

ASTHMATIC SUBJECTS

Ventral-dorsal gradients in the supine posture before the inhalation of a bronchodilator are shown for each patient in figure 6. The gradients of ventilation and V̇/Q̇ were the reverse of those in normal subjects in the same posture, but dorsal perfusion exceeded ventral as in normal subjects. In the horizontal axis (not shown) the V̇/Q̇ gradient was the reverse of normal, cranial V̇/Q̇ exceeding caudal. There were no major changes in these gradients after bronchodilator inhalation. Figure 7 shows transaxial images of ventilation and ventral-dorsal profiles in patient 1 before and after bronchodilatation. Calculation of V̇, Q̇, and V̇/Q̇ from these profiles in terms of the ratios of prebronchodilator to postbronchodilator values is shown in figure 8. In the ventral part of the strip Q̇ increased in relation to V̇ after salbutamol inhalation, leading to a fall of V̇/Q̇. This might explain in part the fall in oxygen saturation after bronchodilator inhalation (table 1).

In the patients V̇ and Q̇ were calculated in 540 regions of interest before and after bronchodilator inhalation (table 4). Fifty eight percent of regions of interest had a higher V̇/Q̇ ratio after bronchodilatation. In 227 regions of interest where the V̇/Q̇ ratio (normalised to an overall V̇/Q̇ of 1) worsened, fractional Q̇ increased in 141; in 92 of those regions of interest V̇ fell and in the remaining 49 V̇ rose but relatively less than Q̇.

Table 4 *Analysis of regions of interest (ROIs)—1.9 cm³ volume in three asthmatic subjects (180 ROIs in each)—after bronchodilator: number of ROIs with higher V̇, Q̇, and V̇/Q̇ after bronchodilator*

Patient No	*V̇*	*Q̇*	*V̇/Q̇*	*V̇ and Q̇*
1	138	96	102	68
2	120	74	123	54
3	104	78	87	30
Total	362	248	312	152
% of all ROIs	67	46	58	28

Discussion

CRITIQUE OF METHODS

The theory of the use of ultrashort half life radioactive gases has been fully described elsewhere.[8 9 11] Briefly, during steady state inhalation of intravenous infusion of krypton 81m the regional (r) count rate (N) as a fraction of the total (N_r/N_{tot}) represents the equilibrium between arrival and removal:

$$N_r/N_{tot} = (F_r/F_{tot}) . (\dot{V}_{tot}/VA_{tot} + \lambda)/(\dot{V}_r/VA_r + \lambda),$$

where F_r/F_{tot} is regional inflow ($\dot{V}$ during inhalation and $\dot{Q}$ during infusion) as a fraction of the total for the lung, $\dot{V}_r/VA_r$ and $\dot{V}_{tot}/VA_{tot}$ are regional and total expiratory ventilation per unit alveolar volume respectively, and λ is the rate of radioactive decay for krypton 81m. To the extent that $\dot{V}_r/VA_r$ is small relative to λ (during resting breathing with a homogeneous distribution of $\dot{V}$ the ratio is about 1:3), the local count rate (N_r) becomes directly proportional to local $\dot{V}$ or $\dot{Q}$. Nevertheless, variations in $\dot{V}_r/VA_r$ will affect the relationship between N_r and $\dot{V}_r$ or $\dot{Q}_r$. The potential errors have been discussed by Ciofetta *et al.*[12] In absolute terms, N_r will be underestimated by 35% when $\dot{V}_r/VA_r$ is 1.5 l/min/l (a normal value) but the relative error between two regions, which will influence the calculation of vertical or horizontal gradients, will be dependent on the value of $\dot{V}_{tot}$. To take the most extreme example from table 2 and figure 3 (the ventilation gradient in the supine posture of 10% per cm lung distance), the gradient has been underestimated by a factor of 0.64 if the dependent zone $\dot{V}_r/VA$ was 4.5 l/min/l and by 0.78 if $\dot{V}_r/VA$ was 1.5 l/min/l. Absolute values of specific ventilation in this zone in the supine posture vary from 1.5[6] to 3.4[13] l/min/l. In the worst case, the gradients of $\dot{V}$ and $\dot{Q}$ shown in figures 3 and 4 and tables 2 and 3 have been underestimated by 20–30%. In the calculation of $\dot{V}/\dot{Q}$ the factor $\dot{V}_r/VA$ is common to $\dot{V}$ and $\dot{Q}$, provided that there is no gross intravoxel inhomogeneity; and this source of error disappears, as shown by Harf *et al.*[10]

Attenuation corrections were not used in this study. The low density of the lung implies that corrections will be small, though locally higher when bony structures (ribs, spine) intervene. The shoulder girdle is a region of relatively high attenuation and all studies were performed with the arms raised above the head. Since the same radionuclide was used for the $\dot{V}$ and the $\dot{Q}$ scans attenuation corrections do not play any part in the $\dot{V}/\dot{Q}$ calculations. More recently, studies were performed in dogs, after intravenous injection of technetium 99 labelled albumin macroaggregates, in which the lungs were tomographed in vivo, and at postmortem examination whole lung sections were scanned in two dimensions. The difference in local distribution between tomographic scanning (without attenuation correction) and planar scanning was small (about 10%) and within the statistical accuracy of both techniques (MJ Myers, personal communication).

The advantage of tomography lies in a more precise definition of local geometry. With two dimensional radioisotope scanning thoracic geometry has had to be defined with a second measurement of alveolar volume, generally by rebreathing of a radioactive gas to equilibrium. Even so, this manoeuvre does not give any resolution in depth. With tomographic scanning $\dot{V}$ and $\dot{Q}$ can be expressed directly per unit of thoracic volume, the size of the unit being dependent on the spatial resolution of the counting system. Because alveolar size and lung density are not constant throughout the lung,[14] "per unit alveolar volume" does not have precisely the same connotation as "per unit thoracic volume," but the differences are not of major importance.

EFFECTS OF POSTURE

Using a double isotope technique (krypton 81m and krypton 85m) Amis *et al*[6 7] measured the distribution of $\dot{V}$, $\dot{Q}$, and $\dot{V}/\dot{Q}$ in the same postures as in this study. With the use of SPECT, their two dimensional measurements have now been extended to three dimensions. There are no major discrepancies between the two studies. More reversal of the vertical gradient of $\dot{V}$ in the prone posture was seen in this tomographic study. Interestingly, the prone posture also behaves eccentrically as regards cranial-caudal gradients (fig 4, table 2), as previously noted.[6 7]

In general, the influence of gravity, acting through regional differences in lung expansion and compliance and on a low resistance vascular circuit, determines the distribution of $\dot{V}$ and $\dot{Q}$ and thus $\dot{V}/\dot{Q}$. Vertical gradients, except in the prone posture, are much more prominent than horizontal gradients and are independent of position (cranial, mid, or caudal) within the lung, $\dot{Q}$ in the lateral decubitus posture being an exception. In the supine and prone postures horizontal gradients are also independent of their position (ventral, mid, or dorsal) within the lung. These cranial-caudal gradients are small; but there are no good explanations for them. Airway closure has been invoked to explain the decrease of $\dot{V}$ caudally in the supine posture since some dependence on lung volume has been found,[15] but the lack of ventral-dorsal differences makes this unlikely in the present study.

The most intriguing finding is loss of a vertical gradient (and slight reversal) of ventilation in the prone posture. The principal motions of the respiratory system are laterally and anteriorly (ventrally). In the prone posture anterior motion is considerably limited, as shown radiographically by a reduction in movement caudally of the ventral position of the

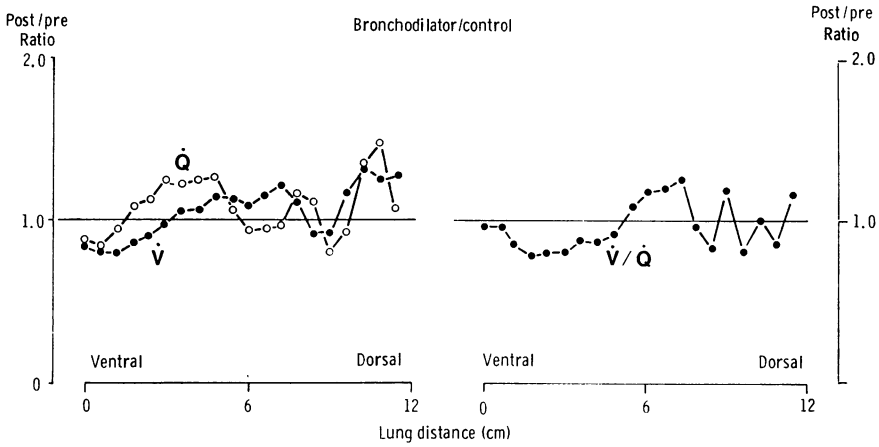

Fig 8 *Analysis of ventilation ($\dot{V}$), perfusion $\dot{Q}$, and $\dot{V}/\dot{Q}$ for ventral-dorsal strip in the same asthmatic subject as in figure 7 presented as ratios of the bronchodilator values to prebronchodilator values. Individual points represent regions 1.24 × 1.24 × 0.62 cm. Note the relative increase of $\dot{Q}$ and decrease of $\dot{V}$ and $\dot{V}/\dot{Q}$ ventrally.*

diaphragm.[16] In the prone suspended posture (hands and knees) the normal vertical gradient of increasing dorsal to ventral ventilation is seen.[17] Thus the constraint of lying on a couch or table is probably responsible for the alteration in the ventilation gradient in the prone (unsuspended) posture.

EFFECTS OF BRONCHODILATORS

Patchy ventilatory abnormalities at lobar or segmental level, as shown in figure 7, are typical of asthma.[18] Gross abnormalities of $\dot{V}$ distribution may appear in two to three minutes if bronchoconstriction is provoked in an asthmatic subject by inhalation of acetylcholine, disappearing just as rapidly after inhalation of β agonist drugs.[19] It is quite common to see small falls of arterial oxygen tension and saturation in asthmatics after bronchodilator inhalation with aminophylline and isoprenaline[20] and considerably increased blood flow to units with low $\dot{V}/\dot{Q}$ (that is, poorly ventilated) has been shown with the multiple inert gas technique.[21] More selective β agonists have little or no effect on arterial oxygen tension in asthma.[22 23] The gross regional changes that followed the inhalation of bronchodilator in the three subjects in this study were not great (figs 7 and 8), though there were subtle changes at a more local level (table 4). An increase in fractional blood flow and worsening of the $\dot{V}/\dot{Q}$ ratio was seen in 92 of the 540 units examined, but the overall effect on ear lobe oxygen saturation was small (table 1).

It is not surprising that the regional distribution of ventilation is more disturbed than blood flow (fig 6) in the asthmatic patients since their disease affects airways much more than blood vessels. The dorsal regions were affected more than the ventral, possibly because airways are likely to be initially narrower in dependent lung regions, where the pressures distending the parenchyma and airways are least. In the asthmatic subjects the effects of posture on regional ventilation have not yet been studied.

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