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Effects of posture on the distribution of pulmonary ventilation and perfusion in children and adults

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ABSTRACT In the adult the distributions of ventilation and of perfusion show the same directional dependence on gravity. In children, however, the distribution of ventilation in response to gravity is the reverse of that seen in adults. The aim of the current study was to determine whether perfusion showed the same reversal in children or followed the adult pattern. Distribution of perfusion was measured with intravenous technetium-99m macroaggregated albumin and distribution of ventilation with inhaled krypton-81m. Eighteen children and seven adults were studied; they had been referred for lung scanning for various respiratory problems. The effect of gravity was examined by giving aliquots of macroaggregated albumin and ^{81m}Kr by inhalation to the subject in the supine and the lateral decubitus position. Counts in the dependent lung were compared with those in the upper lung. The dependent lung in the lateral decubitus position received more of the total perfusion than it did in the supine position in seven children with a normal chest radiograph (mean 7·0%, range 4·8–10·9% more) and in 11 children with an abnormal radiograph (mean 3·4% (0·1–10·0%)). Ventilation, however, changed in the opposite direction, falling by 7·1% (−3·2% to −12·8%) in five children with a normal chest radiograph and 11·2% (−2·8% to −19·3%) in eight children with an abnormal radiograph. Fractional $\dot{V}$/fractional $\dot{Q}$ (an index of the ventilation:perfusion ratio) decreased in the dependent lung in the children when they moved from the supine to the decubitus position. The same directional change was recorded in adults, but it was significantly less than in the children, irrespective of whether the chest radiograph was abnormal. In children and adults with various respiratory problems the effect of posture on the distribution of perfusion is similar.

Introduction

Bronchospirometric[1-4] and radioactive gas[5-7] techniques have shown that under the influence of gravity ventilation and perfusion in the adult are distributed preferentially to the dependent lung in the lateral decubitus position. In children, however, ventilation is distributed preferentially to the upper lung, whether diseased or normal.[8,9] Cohen *et al*[10] applied these findings by treating infants with unilateral pulmonary emphysema in the lateral decubitus position with the normal lung uppermost.

The effect of posture on the pulmonary distribution of perfusion in children has not, however, been investigated. We undertook the current study therefore to compare the distribution of ventilation and perfusion in the lateral decubitus position in children and adults.

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Methods

We studied 18 children (age range 5 months to 11 years; 10 girls, eight boys) and seven adults (age range 29–59 years; five men, two women) during the course of routine ventilation-perfusion ($\dot{V}$-$\dot{Q}$) scintigraphy for various indications (table). All the studies were relevant to the patient's management and performed after routine referral from the clinician. As they did not require any increase in the dose of radioactivity or additional venepunctures (see "Methods") ethical approval was not sought.

For imaging of ventilation the patient inhaled krypton-81m (^{81m}Kr) at rest while in the supine position above a gamma camera (IGE 400 A or Scintronix) fitted with a parallel hole, general purpose, low energy collimator. After a posterior image of the chest had

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Details of the patients studied

Patient No	*Age (y)*	*Sex*	*Weight (kg)*	*Clinical summary*	*Chest radiograph*
CHILDREN					
1	0·5	F	4·5	Dyspnoea	Consolidation RML
2	0·75	M	8·0	Wheezing cough	Normal
3	1·0	M	9·0	Respiratory infection	Normal
4	1·1	M	10·0	Scoliosis	Normal
5	1·2	F	10·2	Pertussis FU	Patchy consolidation LUL
6	1·3	F	10·0	Congenital lobar emphysema	Overinflated LUL
7	1·7	F	11·0	Respiratory infection	Consolidation RUL
8	2·5	M	11·0	Respiratory infection	Normal
9	5·1	F	21·5	Sequestrated segment	Abnormal shadowing LLL
10	6·0	F	22·5	Sequestrated segment	Abnormal shadowing RLL
11	6·5	M	22·0	Cough and sputum	Bilateral subsegmental shadowing
12	7·0	F	24·5	Pneumonia FU	Normal
13	7·5	M	25·5	Pneumonia FU	Patchy consolidation RUL
14	8·5	F	29·0	Foreign body FU	Partial atelectasis LUL
15	9·1	M	27·0	Respiratory infection	Normal
16	10·0	F	31·5	Persistent cough	Normal
17	10·0	M	29·0	Severe immunodeficiency	Bilateral changes of chronic lung disease
18	11·3	F	33·5	Bronchiectasis	Abnormal shadowing RLL
ADULTS					
1	29	M		Bronchiectasis	Consolidation LUL with collapse
2	32	M		Persistent cough	Normal
3	36	F		Blood stained pleural effusion	Bilateral effusions
4	41	M		Suspected PE with normal lung scan	Normal
5	41	M		Dyspnoea	Bilateral linear atelectasis
6	42	F		Cough and fever	Normal
7	59	M		Pneumonia	Abnormal shadowing RUL

LUL—left upper lobe; LLL—left lower lobe; RUL—right upper lobe; RLL—right lower lobe; RML—right middle lobe; FU—follow up; PE—pulmonary embolism.

been acquired the patient was moved to the lateral decubitus position, followed by the camera, and continued to inhale ^{81m}Kr. A second posterior image of the chest was acquired. As it has a half life of only 13 seconds ^{81m}Kr delivers a negligible radiation dose. It is frequently difficult to obtain the cooperation of young children for ventilation imaging with ^{81m}Kr and this had to be abandoned in five of the 18 children.

For imaging of perfusion about one third of the dose (75 MBq/70 kg) of ^{99m}Tc macroaggregated albumin labelled with technetium-99m (^{99m}Tc; Amersham International) was administered intravenously with the patient in the same lateral decubitus position. After a posterior image had been acquired the patient was moved to the supine position, as for the ventilation image, and the remaining two thirds of the macroaggregated albumin was administered through the same intravenous line. Another posterior image was acquired. All images (ventilation and perfusion) contained 200 000 counts. The turnover time of macroaggregated albumin is much longer than the duration of the study. The direction of turning (to left or right decubitus) varied, depending on which side was more convenient in relation to the site of venepuncture.

The images were stored in a computer (MDS A2 or Informatek). Regions of interest were drawn over the right and left lungs. The counts in the lung that was dependent in the decubitus position were expressed as percentages of the total lung counts, both for ventilation and for perfusion images. For perfusion the counts in the preceding decubitus position were subtracted from the counts recorded in the supine position. Because of the very short half life of ^{81m}Kr no subtraction was necessary for the ventilation studies. Fractional ventilation was divided by fractional perfusion to obtain an index of the change in ventilation/perfusion between the two positions.

The significance of changes in ventilation and perfusion between the two positions was calculated by means of the Wilcoxon signed rank test, and between adults and children and between subjects with normal and with abnormal chest radiographs by means of the Wilcoxon rank sum test.

Results

In five children with a normal chest radiograph the percentage of ventilation going to the dependent lung fell by a mean of −7·1 (range −3·2 to −12·8) when they moved from the supine to the lateral decubitus position. The corresponding percentage changes in eight children with an abnormal chest radiograph was −11·2 (range −2·8 to −19·3) ($p < 0·01$). The percentage of perfusion on the other hand increased by 7·0 (range 4·8 to 10·9) ($p < 0·05$) in 7 children with a

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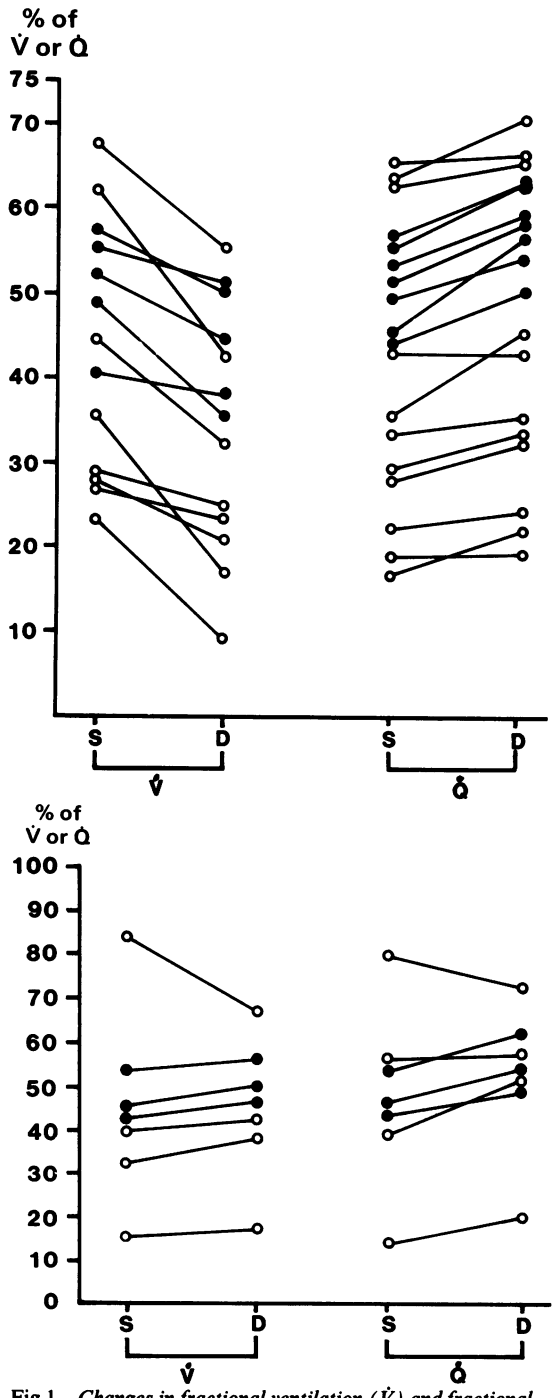

Fig 1 *Changes in fractional ventilation ($\dot{V}$) and fractional perfusion ($\dot{Q}$) in the dependent lung in the lateral decubitus position (D) and the supine position (S) in (a) children and (b) adults with normal (●) and abnormal (○) chest radiographs.*

normal chest radiograph and by 3·4 (range 0·1 to 10·0) ($p < 0·01$) in 11 children with an abnormal chest radiograph. The increase in perfusion in children with a normal chest radiograph was significantly greater than in those with an abnormal chest radiograph ($p < 0·05$). Individual changes are shown in figure 1 for children and for adults. The postural changes that we observed in ventilation and perfusion occurred regardless of whether the dependent lung was more or less abnormal than the upper lung.

The relation between age and change in the distribution of ventilation when subjects moved from the supine to the lateral decubitus position is shown in figure 2.

Fractional ventilation/fractional perfusion in the dependent lung fell from 0·97 (range 0·77–1·11) to 0·73 (0·63–0·86) after the change from the supine to the lateral decubitus position in the five children with a normal chest radiograph and from 1·09 (0·78–1·37) to 0·72 (0·52–1·2) ($p < 0·01$) in the eight with an abnormal chest radiograph. In the seven adults (normal and abnormal chest radiograph) the corresponding change was from 0·97 (0·77–1·1) to 0·89 (0·74–1·01) ($p < 0·05$). This change was significantly less than that seen in children with a normal ($p < 0·01$) or abnormal ($p < 0·001$) chest radiograph.

Discussion

Krypton-81m and technetium-99m macroaggregated albumin are both well accepted agents for the non-invasive study of ventilation and perfusion respectively. The distribution of counts in static images containing 200K counts is, from the viewpoint of counting statistics, an accurate reflection of the distribution of perfusion. The same applies to ventilation, though in very young children (less than 3–6 months of age) the higher ratio of ventilation to lung volume causes the counts to become more volume dependent than ventilation dependent. The ^{99m}Tc macroaggregated albumin and ^{81m}Kr images give no information on absolute values of pulmonary blood flow or ventilation, showing only their relative distribution. We cannot therefore measure ventilation:perfusion ratios. Change in fractional ventilation and fractional perfusion give information on relative changes in ventilation:perfusion ratios.

In the erect adult alveolar pressure in the upper zones exceeds both pulmonary arterial and pulmonary venous pressures, so there is little or no blood flow. In the mid zones alveolar pressure is intermediate between arterial and venous pressures and blood flow is proportional to the difference between pulmonary arterial and alveolar pressure. In the dependent zones, where both arterial and venous pressures are higher than alveolar pressure, blood flow is proportional to

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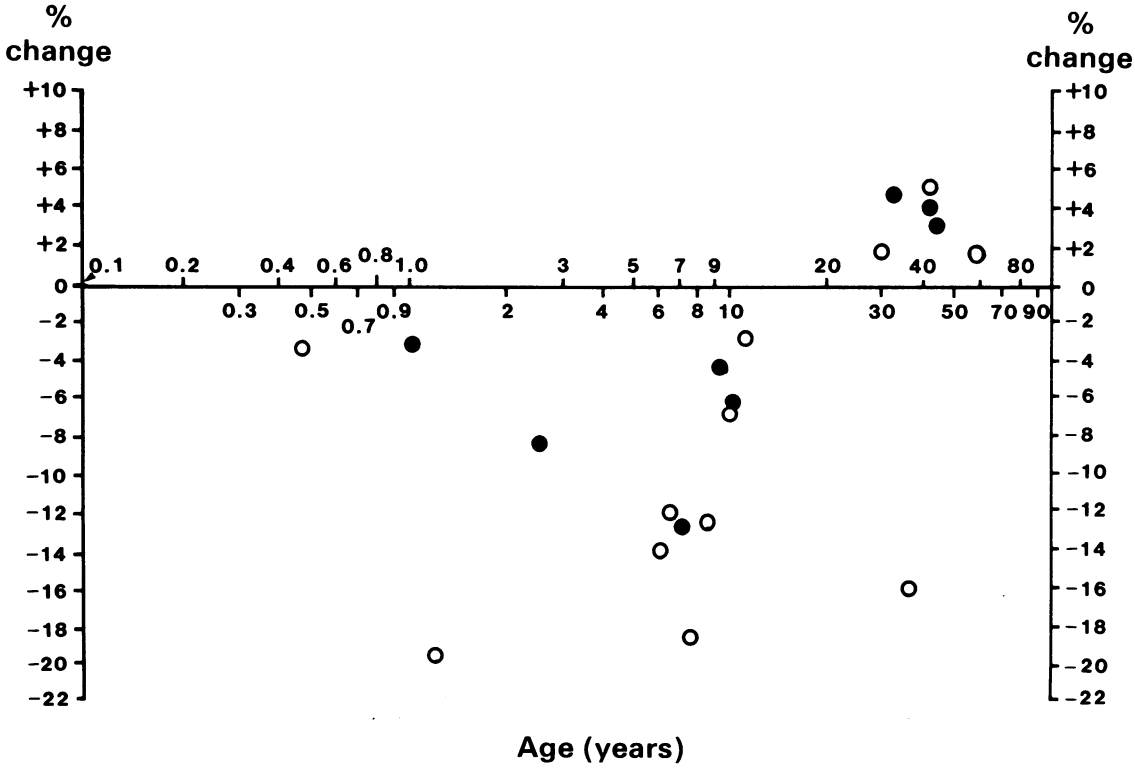

Fig 2 *Effect of age on the fractional change in the percentage of total ventilation supplying the dependent lung when the subject moved from the supine position to the lateral decubitus position. (●) Normal chest radiograph; (○) abnormal chest radiograph.*

the arteriovenous pressure difference. This explains the gravity dependent distribution of perfusion. This gravitational gradient also applies to the lateral decubitus position.[11 12] Our results show that perfusion in the child shows a gravity dependent distribution similar to that seen in adults.

Regional differences in transpulmonary pressure (the difference between intrapleural and intra-alveolar pressures) account for the regional distribution of ventilation. Alveolar pressure is more or less the same from the top to the bottom of the lung, whereas intrapleural pressure has a vertical gradient, becoming increasingly subatmospheric (negative) towards the top. As a result alveoli at the top of the lung have a higher volume at functional residual capacity (FRC) and are less compliant than units lower down the lung.[13–15]

On the other hand, with increasingly positive intrapleural pressure in the dependent lung regions peripheral airways tend to close. In adults chest wall and lung compliances are similar,[16] whereas in infants and children chest wall compliance is two to three times greater than lung compliance.[17] Peripheral airway closure is therefore particularly evident in young children, as mean intrapleural pressure is less negative than in older subjects. This is reflected in the higher closing volume found in young children.[18] These differences between children and adults have been postulated by Heaf *et al*[8] as the reason for the lower ventilation in the dependent lung in children.

A further explanation is based on the effect of the intra-abdominal contents on the hemidiaphragms. Because the dependent diaphragm is more stretched in expiration in the lateral decubitus position it shows greater contractility, contributing to the greater ventilation in the dependent lung. This effect is likely to be less pronounced in children because the smaller abdominal dimensions should result in a much reduced preload on the dependent diaphragm.[8]

An alternative explanation for the difference in the distribution of ^{81m}Kr seen in children is that because of their higher ratio of ventilation to lung volume the ^{81m}Kr signal is no longer independent of lung volume and no longer therefore a marker for ventilation.[19] This only applies to the very young infant, however, yet the pattern of redistribution of ventilation in

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response to gravity continues to be seen in children up to prepubertal age (fig 2).

In summary, this study has confirmed a fundamental difference in the effect of gravity on ventilation in children and adults lying on their side. The effect of gravity on perfusion, however, is qualitatively similar in children and adults. This apparent "imbalance" in children may have clinical importance. The postural changes that we observed in ventilation and perfusion occurred regardless of whether the dependent lung was more or less abnormal than the upper lung. Pathological conditions did not therefore appear to obscure this physiological phenomenon. The pathophysiological mechanisms and clinical implications require further investigation.

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