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 81mKr 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 70%, 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 V/fractional 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

Bronchospirometric1-4 and radioactive gas5-7 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 al10 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.

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 (V-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 (81mKr) 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

<table>
<thead>
<tr>
<th>Patient No</th>
<th>Age (y)</th>
<th>Sex</th>
<th>Weight (kg)</th>
<th>Clinical summary</th>
<th>Chest radiograph</th>
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<td>Consolidation RML</td>
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<tr>
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<td>3</td>
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<td>9-0</td>
<td>Respiratory infection</td>
<td>Normal</td>
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<tr>
<td>4</td>
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<td>M</td>
<td>10-0</td>
<td>Scoliosis</td>
<td>Normal</td>
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<td>5</td>
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<td>10-2</td>
<td>Pertussis FU</td>
<td>Patchy consolidation LUL</td>
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<td>1-3</td>
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<td>Congenital lobar emphysema</td>
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<tr>
<td>7</td>
<td>1-7</td>
<td>F</td>
<td>11-0</td>
<td>Respiratory infection</td>
<td>Consolidation RUL</td>
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<tr>
<td>8</td>
<td>2-5</td>
<td>M</td>
<td>11-0</td>
<td>Respiratory infection</td>
<td>Normal</td>
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<tr>
<td>9</td>
<td>5-1</td>
<td>F</td>
<td>21-5</td>
<td>Sequestrated segment</td>
<td>Abnormal shadowing LLL</td>
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<tr>
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<td>6-0</td>
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<td></td>
<td>Bronchectasis</td>
<td>Consolidation LUL with collapse</td>
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<tr>
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<td>M</td>
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<td>Normal</td>
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<tr>
<td>3</td>
<td>36</td>
<td>F</td>
<td></td>
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<td>Bilateral effusions</td>
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<tr>
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<td>M</td>
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<td>Suspected PE with normal lung scan</td>
<td>Normal</td>
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<td>Bilateral linear atelectasis</td>
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<tr>
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<td></td>
<td>Cough and fever</td>
<td>Normal</td>
</tr>
<tr>
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<td>49</td>
<td>M</td>
<td></td>
<td>Pneumonia</td>
<td>Normal</td>
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</tbody>
</table>

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 81mKr. A second posterior image of the chest was acquired. As it has a half life of only 13 seconds 81mKr delivers a negligible radiation dose. It is frequently difficult to obtain the cooperation of young children for ventilation imaging with 81mKr 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 99mTc macroaggregated albumin labelled with technetium-99m (99mTc; Amer- sham 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 81mKr 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
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 distribu-
tion 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 corre-
spending 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 respect-
ively. The distribution of counts in static images 
containing 200K counts is, from the viewpoint of 
counting statistics, an accurate reflection of the dis-
tribution 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 macroag-
ggregated albumin and 81mKr images give no informa-
tion 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 be-
tween 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 al8 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 81mKr seen in children is that because of their higher ratio of ventilation to lung volume the 81mKr 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
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.

AMP was supported by the Wellcome Trust.

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Effects of posture on the distribution of pulmonary ventilation and perfusion in children and adults.
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Thorax 1989 44: 480-484
doi: 10.1136/thx.44.6.480

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