Position affects distribution of ventilation in the lungs of older people: an experimental study

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Question: What is the effect of sitting and side-lying on the distribution of ventilation during tidal breathing in healthy older people? Design: Randomised, within-participant, experimental study. Participants: Ten healthy people more than 65 years old. Intervention: Tidal breathing during sitting and right side-lying. Outcome measures: Distribution of ventilation as a percentage of total counts using Technetium-99m Technegas lung ventilation imaging. Results: In sitting, the ratio of the distribution of ventilation to apical: middle: basal regions was 1: 3.5: 3.3 in the right lung, and 1: 2.9: 2.3 in the left lung. In right side-lying, 32% (95% CI 22 to 43) more ventilation was distributed to the right lung than to the left lung. The ratio of the distribution of ventilation to apical: middle: basal regions was 1: 2.8: 2.2 in the right lung, and 1: 2.4: 1.9 in the left lung. Conclusions: In both sitting and right side-lying, ventilation was distributed more to the middle than to the basal region, which may be related to age-associated changes in the respiratory system. [Krieg S, Alison JA, McCarren B, Cowell S (2007) Position affects distribution of ventilation in the lungs of older people: an experimental study. Australian Journal of Physiotherapy 53: 179–184]

Key words: Pulmonary ventilation, Radionuclide imaging, Technegas, Posture, Aged

Introduction

Physiotherapists alter the position of patients in order to affect changes in the distribution of ventilation (Brooks et al 2001). Many patients requiring such intervention are in the older age group (AIHW 2006). However, there are limited reports of the effects of positioning on the distribution of ventilation in this age group.

There is evidence that altering the position of the thorax, for example from upright to side-lying, alters the distribution of ventilation in the lungs of younger subjects (Amis et al 1984, Demedts 1980, Dollfuss et al 1967, Kaneko et al 1966, Milic-Emili et al 1966) such that ventilation is preferentially distributed to the gravity-dependent region of the lungs. Distribution of ventilation in younger subjects has also been shown to alter with changes in inspiratory flow rate (Bake et al 1974, Martin et al 1972), initial lung volume prior to inspiration (Grant et al 1974, Robertson et al 1969), changes in chest wall shape induced by the pattern of respiratory muscle recruitment (Chevrolet et al 1979, Engel et al 1980, Roussos et al 1977a), and obesity (Demedts 1980). The distribution of ventilation in the lungs of older people may be affected by age-associated changes in the respiratory system (Tucker and Jenkins 1996). The static elastic recoil pressure of the lung decreases with age (0.1 to 0.2 cmH₂O/ year) (Niewohner et al 1975, Turner et al 1968), resulting in an increase in closing capacity, ie, the lung volume at which there is closure of the small airways in the gravity dependent lung regions during tidal breathing (Leblanc et al 1970). Closing capacity has been shown to equal or exceed functional residual capacity as early as 66 years in the upright position and at an earlier age (approximately 44 years) in recumbent positions (Leblanc et al 1970, McCarthy et al 1972). Thus ageing may result in some lung unit closure in the gravity-dependent lung regions during normal tidal breathing (Leblanc et al 1970), which could potentially result in preferential ventilation of regions that are less gravity dependent, however, this has not been substantiated.

The only previous studies examining the distribution of ventilation in older subjects measured the distribution of ventilation during maximal inspiration from either residual volume or functional residual capacity (Demedts 1980, Holland et al 1968). However, as resting tidal breathing is the most common pattern of breathing for people confined to bed we sought to evaluate the distribution of ventilation during tidal breathing in the older age group in different positions. This study may provide evidence for altering position in older people to improve ventilation and gas exchange. The research questions for this study were: in older people

1. What is the distribution of ventilation during tidal breathing in sitting?
2. What is the distribution of ventilation during tidal breathing in side-lying?
3. What is the difference in distribution of ventilation between sitting and side-lying?

Method

Design

The design was a repeated-measures, within-participant, experimental study in which two positions were examined: sitting and right side-lying. The order of positions for each subject was randomised using a computerised random number generation program. Participants were measured in each position a day apart. The study was approved by the South Western Sydney Area Health Service Ethics Committee and The University of Sydney Human Ethics
Committee. Written informed consent was obtained from all participants prior to testing.

Participants
Healthy adults were included if they were 65 years and older, were non-smokers or ex-smokers with normal spirometry, had no history of cardiorespiratory disease, and had a body mass index less than 30 kg/m².

Intervention
Tidal breathing was examined in sitting or right side-lying. For sitting, participants sat on the edge of a bed with their feet supported and their back unsupported. They were instructed to ‘sit tall’. For side-lying, participants lay on their right side fully supported.

Outcome measures
The distribution of Technegas in the lungs was quantified by performing a lung ventilation scan using Technetium-99m as Technegas. Technegas has been shown to reflect a similar distribution of ventilation as the radioactive gases Krypton-81m (Burch et al 1986, Isawa et al 1994, Watanabe et al 1995) and Xenon-133 (Amis et al 1990). In addition, Technegas has been used to evaluate regional ventilation in healthy subjects (King et al 1997, King et al 1998, Petersson et al 1998, Tucker et al 1999) and people with asthma (Petersson et al 1998).

The administration of Technegas to the subject was via a circuit made up of two patient administration sets(a) connected by a rubber T-piece to a facemask (Figure 1). Each patient administration set consisted of inspiratory tubing, a filter, and a one-way expiratory valve to direct expired Technegas into the filter to prevent contamination of the Technegas generator and room-air.

The first patient administration set was connected to the Technegas generator to deliver Technegas to the subject. The inspiratory tubing of the second patient administration set was open to room-air, which allowed the participants to breathe room air between inspirations of Technegas to prevent oxygen desaturation. Vascular clamps were used to occlude the inspiratory lines of the Technegas patient administration set and the room-air patient administration set at separate times throughout the pattern of breathing to allow the sole inspiration of either Technegas or room-air. The timing of clamping and unclamping is detailed further in Figure 2. The pattern of breathing required for the intermittent inspiration of Technegas was normal tidal breathing (Figure 2). As the dead space of the tubing was measured, via water volume, to be approximately 150 ml, participants were instructed to perform a slightly increased expiration, approximately 150 ml below functional residual capacity prior to the first inhalation of Technegas so that the subsequent inspiration cleared the dead space of the Technegas inspiratory tubing. This was to ensure that participants were inspirating Technegas from functional residual capacity. After the first breath of Technegas, this additional expiratory volume was not required as Technegas was now available at the mouth for subsequent inspirations.

The tidal inspiration of Technegas was followed by a five-second breath hold. The breath hold was incorporated to aid the deposition of Technegas particles in the alveoli (Ball et al 1962). This breath hold therefore minimised the number of breaths of Technegas required to achieve an appropriate count rate of radioactivity in the lungs. This single cycle of room-air breathing, tidal inspiration of Technegas, and five-second breath hold was repeated six to eight times to ensure adequate deposition of Technegas for lung scanning. An initial gamma camera measurement was made to verify that sufficient Technegas had been inhaled for scanning. If inadequate, participants repeated additional cycles until a count rate of approximately 1000 counts/second was achieved. The effective dose of radiation to the subject was approximately 0.6 milliSieverts per scan.

Prior to each testing session, participants were familiarised with the equipment and trained in the pattern of breathing required on the simulated circuit shown in Figure 1. During training of the pattern of breathing, a calibrated respirometer(b) was attached to the expiratory port of the Technegas patient administration set to monitor and measure expiratory tidal volume and to provide feedback to the participants on tidal breathing as shown in Figure 1.

Data analysis
All scans were acquired with a dual head gamma camera(c). Following the administration of Technegas, participants were scanned in supine with both arms raised above their heads. Due to the deposition properties of Technegas, this repositioning did not alter the distribution of Technegas achieved during administration (Amis et al 1990).

Anterior and posterior images of the lungs totalling 500 000 counts were acquired. The gamma camera was interfaced to a computer system(d), and all images were acquired using a 256 x 256 matrix (ie, 65 536 pixels per image). Nuclear Medicine Imaging System for Windows(e) was used for quantitative analysis of the images. This software allowed the left and right lung to be outlined individually, and then divided into regions of interest.

A standardised procedure was used to define six reproducible regions in each lung (Figure 3). These regions of interest were initially drawn over the posterior view of the upright sitting image for each subject. These regions were then copied and

Figure 1. Simulated circuit on which subjects were trained in the pattern of breathing prior to testing. A respirometer was attached to the expiratory filter of the Technegas patient administration set to measure expiratory tidal volume.
The reliability of the manual drawing technique, based on repeated measures over three separate days was \( r > 0.98 \). The software was able to calculate the total number of counts in each region, which was relative to the distribution of ventilation in that region (Amis et al 1990, King et al 1998).

The posterior image was used for analysis in preference to the anterior image to minimise the attenuation of the \( 99mTc \) gamma emissions by the heart. This method of lung ventilation scan analysis was similar to that used previously (King et al 1997, Tucker et al 1999).

The distribution of ventilation was quantified by the number of counts in each region expressed as a percentage of the total counts (total counts = counts in left lung + counts in right lung) and expressed as a percentage. The percentage of total counts in each of the defined regions was compared within one position and between positions of upright sitting and right side-lying. As the lung regions were defined by geometrical analysis it was not possible to know the relative anatomical size of the lung regions. However, the analysis allowed comparison of these regions in terms of the amount of Technegas deposited in each region which was a product of the anatomical size of the region as well as the distribution of ventilation to the region. The investigator analysing the data was not blind to the participant’s position.

Based on previous data (Tucker et al 1999), five subjects were required to provide 90 percent probability of adequate power (\( \alpha = 0.05 \)) to detect a 12 percent difference in distribution of ventilation.

**Results**

**Participants**

Ten participants were recruited. Their age, body mass index and lung function are shown in Table 1.

**Distribution of ventilation in sitting**

The cranial-caudal and lateral-medial distribution of ventilation to the right and left lung in sitting is presented in Table 2. Ventilation was 9% (95% CI 4 to 14) greater to the right lung compared to the left lung in sitting. For the

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**Table 1. Mean (SD) characteristics of participants.**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n = 20</th>
</tr>
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<tbody>
<tr>
<td>Age (yr)</td>
<td>71.5 (3.9)</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>24.8 (2.5)</td>
</tr>
<tr>
<td>FEV(_1) (%pred)</td>
<td>99 (6)</td>
</tr>
<tr>
<td>FVC (%pred)</td>
<td>99 (10)</td>
</tr>
<tr>
<td>FEV(_1)/FVC</td>
<td>0.75 (0.06)</td>
</tr>
<tr>
<td>Tidal volume in sitting (ml)</td>
<td>422 (84)</td>
</tr>
<tr>
<td>Tidal volume in side-lying (ml)</td>
<td>432 (60)</td>
</tr>
</tbody>
</table>

BMI = body mass index, FEV\(_1\) = forced expiratory volume in one second, %pred = % predicted, FVC = forced vital capacity
cranial-caudal distribution of ventilation, more ventilation was distributed to the middle and basal regions compared to the apical region. The ratio of the distribution of ventilation to apical: middle: basal regions was 1: 3.5: 3.3 in the right lung, and 1: 2.9: 2.3 in the left lung. For the lateral-medial distribution of ventilation, ventilation was distributed equally to the lateral and medial regions. The ratio of the distribution of ventilation to lateral: medial regions was 1: 1.1 in the both the right and left lung.

**Distribution of ventilation in side-lying**

The cranial-caudal and lateral-medial distribution of ventilation to the right and left lung in right side-lying is presented in Table 2. Ventilation to the right lung was 11% (95% CI 7 to 16) less in sitting than in side-lying. For the cranial-caudal distribution of ventilation to the right lung, ventilation was decreased to the apical and middle regions but not to the basal region in sitting compared with side-lying. For the lateral-medial distribution of ventilation to the right lung, ventilation was decreased to both the lateral and medial regions in sitting compared with side-lying.

<table>
<thead>
<tr>
<th>Lung region</th>
<th>Lung side</th>
<th>Positions</th>
<th>Difference between positions</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Sitting</td>
<td>Right side-lying</td>
</tr>
<tr>
<td>Cranial-caudal distribution (% total counts)</td>
<td></td>
<td></td>
<td>Sitting minus right side-lying</td>
</tr>
<tr>
<td>Apical</td>
<td>R</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>7</td>
<td>7</td>
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<td></td>
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<td>(3)</td>
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<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
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<tr>
<td>Middle</td>
<td>R</td>
<td>24</td>
<td>31</td>
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<tr>
<td></td>
<td>L</td>
<td>21</td>
<td>16</td>
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<tr>
<td></td>
<td></td>
<td>(2)</td>
<td>(4)</td>
</tr>
<tr>
<td>Basal</td>
<td>R</td>
<td>23</td>
<td>24</td>
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<tr>
<td></td>
<td>L</td>
<td>17</td>
<td>11</td>
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<tr>
<td></td>
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<td>(3)</td>
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<tr>
<td>Lateral-medial distribution (% total counts)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Lateral</td>
<td>R</td>
<td>26</td>
<td>33</td>
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<tr>
<td></td>
<td>L</td>
<td>22</td>
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<td>(3)</td>
<td>(4)</td>
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<tr>
<td>Medial</td>
<td>R</td>
<td>28</td>
<td>33</td>
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<td>L</td>
<td>24</td>
<td>18</td>
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**Discussion**

This study is the first to examine the spatial distribution of ventilation during tidal breathing in older people in sitting and side-lying using Technegas. The main findings were that in sitting, more ventilation was distributed to the dependent (middle and basal) regions of both lungs than to the non-dependent (apical) regions. In right side-lying, more ventilation was distributed to the dependent (right) lung than to the non-dependent (left) lung.
similar to previous findings in younger adults whereby a tidal inspiration in the upright position was preferentially distributed to the dependent lung regions (Amis et al 1984, Ball et al 1962, Bryan et al 1964, Kaneko et al 1966). This distribution of ventilation is mainly due to the effects of the gravity-dependent gradient in pleural pressure and its relationship to the pressure-volume curve (Milic-Emili 1966).

In the current study, there was less ventilation in the basal region than in the middle region. A previous study in younger adults (mean age 33 years) showed preferential distribution of ventilation to the basal region of the left lung during tidal breathing in sitting (Amis et al 1984). Unfortunately, the study did not report the distribution of ventilation in the middle region of the lungs which would allow comparison between the middle regions in the current study with those in younger adults. Rather, they described the distribution of ventilation comparing the cranial (apical) 20–30% to the caudal (basal) 20–30% in the left lung only. Our finding of a preferential distribution of ventilation to the middle regions of older lungs, especially in the left lung, indicates a distribution of ventilation to regions of the lung that are not as gravity dependent as the basal regions. This appears different from the results in younger adults (Amis et al 1984, Ball et al 1962, Bryan et al 1964, Kaneko et al 1966). However, these studies have defined the lung regions as dependent and non-dependent rather than apical, middle, and basal, making comparisons difficult. The preferential distribution of ventilation to the middle region in older subjects may be the result of age-associated changes in the respiratory system (Leblanc et al 1970, McCarthy et al 1972, Tucker and Jenkins 1996) in which lung unit closure may occur in the gravity-dependent lung regions during normal tidal breathing in the upright position in people older than 65 years (Leblanc et al 1970). The clinical implication of these findings is that to improve distribution of ventilation to the basal region of the lung in the older person, a more non-dependent position for this lung region may be required.

**Distribution of ventilation in side-lying**

The right (dependent) lung received approximately twice the distribution of ventilation compared with the left (non-dependent) lung in right side-lying. This difference was greater than the difference in distribution of ventilation between the left and right lung observed in sitting due to the overall smaller size of the left lung. Many studies have measured the distribution of ventilation in right side-lying in younger adults and shown that ventilation is preferentially distributed to the right (dependent) lung in similar proportions to that found in our study (Amis et al 1984, Kaneko et al 1966, Roussos et al 1977a, Svanberg 1957).

Preferential distribution of ventilation to the right (dependent) lung in right side-lying, seen in younger subjects and in the present study, can be explained by a number of mechanisms. One such mechanism is associated with increased doming of the right (dependent) hemidiaphragm in right side-lying due to abdominal encroachment which places the diaphragm in a mechanically-advantageous position, potentiating an increase in caudal movement during inspiration (Barach and Beck 1954). In addition, the pattern of diaphragmatic contraction has been proposed to lift the mediastinum from the dependent lung, resulting in greater ventilation of the dependent lung (Roussos et al 1977a and 1977b, Svanberg 1957). Furthermore, the pleural-pressure gradient will contribute to a vertical gradient in the distribution of ventilation, from superior to inferior across the lung in side-lying.

A cranial to caudal gradient in the distribution of ventilation was maintained in both lungs in right side-lying. There was a greater distribution of ventilation to the middle region in both the left and right lung. This greater ventilation of the middle region could be the result of basal airway closure associated with ageing and is supported by the finding that there was no difference in ventilation of the basal region of the right lung between sitting and right side-lying. By contrast, in younger adults, a relatively uniform cranial-caudal distribution of ventilation in the left (non-dependent) lung in right side-lying has been shown (Amis et al 1984). Studies in micro gravity have shown that there may be a residual pleural-pressure gradient in the absence of gravity (Guy et al 1994) as a result of the elasticity of the lung and the shape of the chest wall. The gradual decrease in lung elasticity due to ageing may also help to explain the greater distribution to the middle region compared to the basal region. The clinical implication of these findings is that placing an older person in right side-lying will increase the ventilation to the middle region of the right lung but will not significantly alter the ventilation of the basal region. Therefore to improve distribution of ventilation to the basal region of the dependent lung in the older patient, a more non-dependent position for this lung region may be required. This needs to be confirmed by further studies.

A limitation of this study was the lack of a control group of young healthy adults. Rather, we have compared our data to that reported from studies which used slightly different outcome measures. Another limitation was that the tidal volumes reported were not measured directly during Technegas inhalation as this would have contaminated the respirometer. Instead, tidal volumes reported were those recorded during the training session immediately prior to each Technegas inhalation session. As such, these tidal volumes most likely reflect those during the inhalation of Technegas.

In conclusion, the ventilation in the lungs of older healthy people was distributed more to the middle and basal regions in sitting. In right side-lying, ventilation was distributed more to the dependent (right) lung than to the non-dependent (left) lung and to the middle and basal regions of the right lung. Interestingly, in both sitting and right side-lying, ventilation was distributed more to the middle than to the basal region, which may be related to age-associated changes in the respiratory system.

**Footnotes:** (a) Vita Medical Ltd, Australia (b) Wright Respirometer, England (c) MS2 or ECAM, Siemens, Germany (d) Macintosh Apple ICON, Siemens, Germany (e) Version 4.1.86, RadSoft Pty Ltd, Australia.

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References


