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Regional lung function in asbestos workers

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Seaton, D. (1977). *Thorax*, **32**, 40–44. **Regional lung function in asbestos workers.** Regional lung function was measured using radioactive xenon-133 in a group of normal subjects and in two groups of asbestos workers. When compared with the normal group, patients with pulmonary asbestosis showed impaired ventilation of the lower zones. Subjects with calcified pleural plaques without radiological evidence of lung parenchymal fibrosis did not show this abnormality.

Inhaled asbestos particles may produce progressive lung fibrosis and pleural fibrosis with the formation of calcified plaques. Asbestos is exceptional among inhaled dusts in that the lesions, whether pulmonary or pleural, are predominantly basal in distribution (Spencer, 1968). As considerable ventilation-perfusion inequalities have been described in asbestosis following measurements of the respiratory quotient in expired air (Read and Williams, 1959), the present work set out to determine whether regional abnormalities of ventilation or perfusion were demonstrable by lung scanning using radioactive xenon-133 and also to ascertain whether the site of any such abnormalities correlated with the usual pathological distribution of the lesions. Two groups of asbestos workers were studied—those with pulmonary asbestosis and those in whom the lesions were apparently confined to the pleura.

Subjects

The control group consisted of nine normal subjects having a mean age of 60 years. None of them had a history of respiratory disease and their ventilatory capacities, lung volumes, gas transfer factors, and chest radiographs were normal. All were life-long non-smokers. Eleven patients with an average industrial exposure to asbestos dust of 30 years and a mean age of 61 years were studied. They had no clinical features suggestive of chronic bronchitis (MRC Committee on Research into Chronic Bronchitis, 1966) and none had a forced expiratory volume in one second to forced vital capacity ratio of less than 70%. All except one were currently non-smokers, although four had smoked until 10 years previously. They were divided into two groups. Group 1 included six subjects with chest radiographic appearances consistent with asbestosis (UICC Committee, 1970) and at least three of the following features: end-inspiratory basal crepitations, finger clubbing, total lung capacity less than 80% of the predicted value, a transfer factor for carbon monoxide less than 70% of the predicted value. Group 2 consisted of five subjects with chest radiographic appearances consistent with bilateral calcified pleural plaques without evidence of lung parenchymal fibrosis. They had no end-inspiratory crepitations, finger clubbing, or reduced gas transfer factor. The mean ages, duration of exposure to asbestos, and past tobacco consumption, based on the concept of 'pack years', did not differ significantly for these two groups.

Methods

The forced vital capacity and forced expiratory volume in one second were measured using a Pulmometer (Godart). Residual volume was obtained by the helium dilution technique (Bates and Christie, 1950) and the transfer fatcor for carbon monoxide by the single breath method of Ogilvie *et al.* (1957).

Regional lung function was studied by scanning the lungs supine using paired scintillation counters mounted on a movable gantry (Brown *et al.*, 1969). Four scans were performed in each subject during breath holding, after a slow maximal inspiration from functional residual capacity (Dollery and Gillam, 1963). The first displayed the regional distribution of a single breath of inhaled

xenon. The second, by allowing the subject to equilibrate with a xenon gas in air mixture contained in a spirometer, displayed the regional distribution of lung volume. The third displayed the regional distribution of pulmonary arterial perfusion, after an intravenous injection of xenon gas in solution. After the perfusion scan the subjects were allowed to breathe normally for 30 seconds, after which the final scan displayed the regional ability of the lungs to wash out xenon.

In order to express the results, the length of each lung was divided into three equal zones. Length was determined from the points of steep rise and fall in counts as the scanning apparatus moved over the lungs on the equilibration scan. Zonal indices for the regional distribution of inhalation, perfusion, and retention of xenon were derived using the following equations:

$$\dot{V}r\ (alv) = \frac{CRr(inh) \times \Sigma CRr(eq) \times 100}{CRr(eq) \times \Sigma CRr(inh)}$$

$$\dot{Q}r\ (alv) = \frac{CRr(inj) \times \Sigma CRr(eq) \times 100}{CRr(eq) \times \Sigma CRr(inj)}$$

$$\dot{V}r'\ (alv) = \frac{CRr(30\ sec) \times \Sigma CRr(inj) \times 100}{CRr(inj) \times \Sigma CRr(30\ sec)}$$

where:

$\dot{V}r(alv)$ is the index of regional ventilation per alveolus on single breath inhalation;

CRr(inh) is the regional count rate after single breath inhalation;

CRr(eq) is the regional count rate after equilibration with xenon;

$\dot{Q}r(alv)$ is the index of regional perfusion per alveolus;

CRr(inj) is the regional count rate after i.v. xenon gas in solution;

$\dot{V}r'(alv)$ is the index of regional retention per alveolus after the washout procedure;

CRr(30 sec) is the regional count rate after the washout procedure.

Thus the distribution ratio for each zone has been expressed as a percentage of the mean distribution ratio for the whole lung. Even distribution of counts in each scan would therefore give an index of 100 for each zone.

Results

The results for the normal subjects are illustrated in Figure 1. A single inhaled breath of xenon was distributed equally to the lower and middle zones, with an apparent decrease in the upper zone (upper zone *v* lower zone, $P<0.01$). After injection of xenon gas in solution, a gradient of increasing perfusion per alveolus from lower to upper zone was shown (upper zone *v* lower zone, $P<0.001$). There was no significant difference in the distribution of retained counts after washout, between the

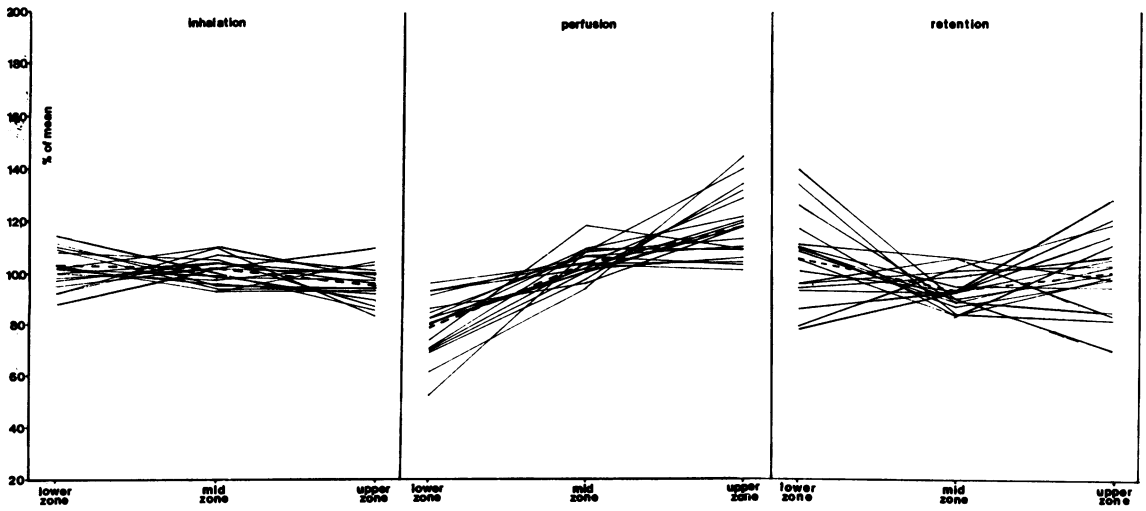

Fig.1 *Distribution indices in nine normal subjects.*

lower and upper zones, although counts were reduced in the middle zone ($P<0.01$ and <0.05 respectively).

The results or the subjects in group 1 are shown in Figure 2. The zonal distribution per alveolus of inhaled and injected xenon do not differ significantly from the control group. There are, however, pronounced abnormalities in the pattern of interzonal retention of injected xenon after the washout procedure. A gradient is seen from lower zone to upper zone with greater retention of xenon in the lower zone (upper zone lower zone, $P<0.001$).

The results of the subjects in group 2 are shown in Figure 3. The interzonal distribution of inhaled xenon did not differ significantly from the control group or group 1. After injection of xenon, the steep gradient of pulmonary perfusion from the lower to the upper zone observed in the control group and group 1 was not seen, and

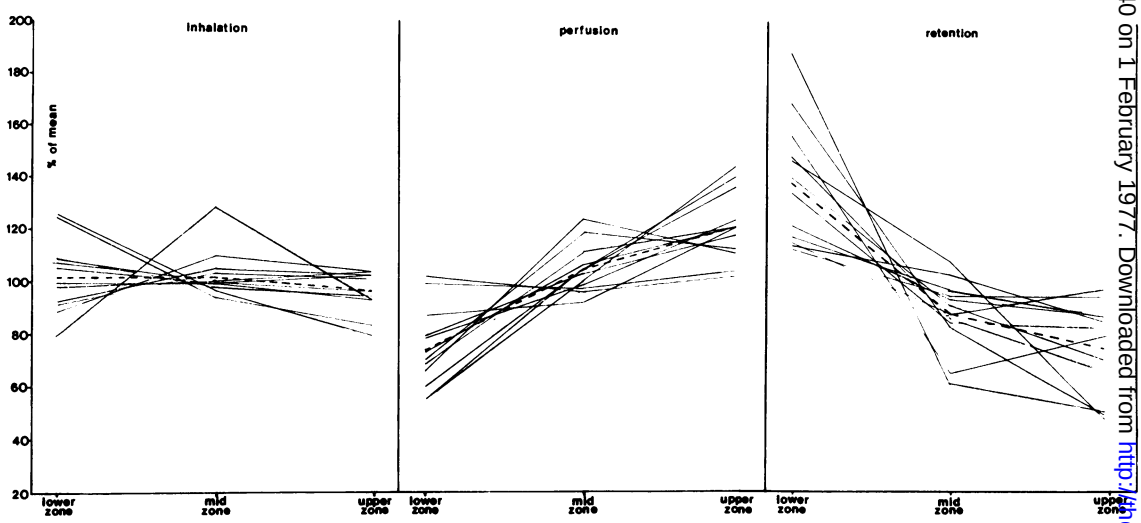

Fig. 2 *Distribution indices in six patients with parenchymal asbestosis.*

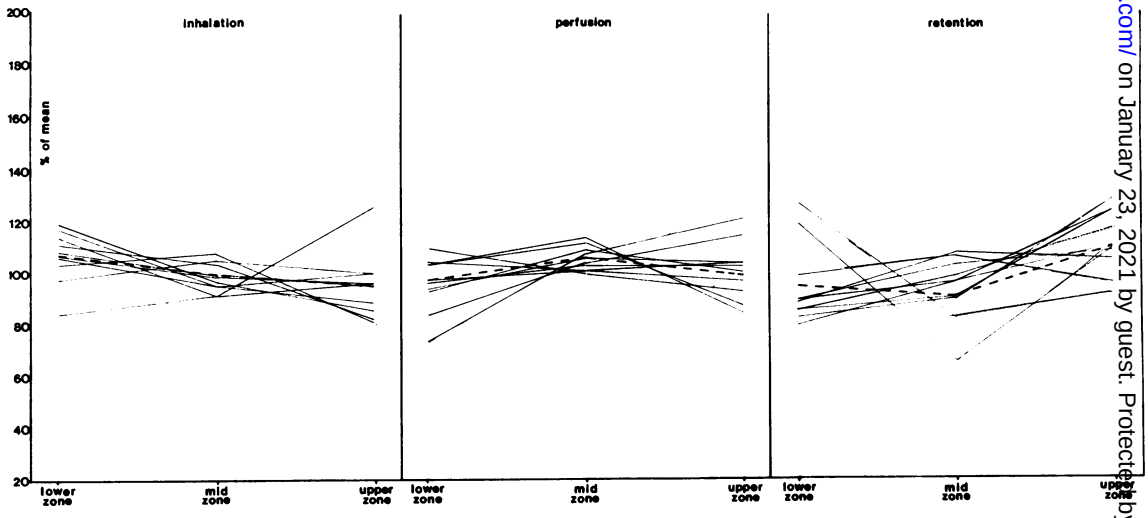

Fig. 3 *Distribution indices in five patients with pleural asbestosis.*

after the washout procedure there was slightly greater retention of xenon in the upper than the lower zone ($P<0.02$).

Discussion

NORMAL SUBJECTS

Previous studies of younger normal subjects in the supine position have shown that a single inhaled breath of xenon is distributed evenly along the longitudinal axis of the lung (Bryan *et al.*, 1964); Kaneko *et al.*, 1966). As the ages of the nine normal subjects scanned in the present study ranged from 49 to 75 years, their dependent small airways will have tended to close at lung volumes greater than functional residual capacity (McCarthy *et al.*, 1972). The tilt of the longitudinal axis of the lungs in the supine posture results in the apices being slightly more dependent than the bases. A greater number of small airways per unit lung volume might therefore be closed at functional residual capacity in the upper zone than in the lower, due to the gravity-dependent vertical gradient of pleural pressure. This would explain the reduced upper zone inhalation index in the control group. In normal subjects, the proportion of injected xenon retained after the washout procedure is low, and this may have the effect of increasing the fractional contribution of chest wall radiation to the total number of recorded counts. If this extrapulmonary activity were distributed evenly along the length of the chest, washout of xenon would be apparently better in the middle zone than in the upper or lower zones, because although the lung has been divided into three zones of equal length, the lung volume of the middle zone exceeds the volumes of the upper and lower zones respectively, and the count rate from middle zone lung is therefore higher. This was the case in the control group. In diseased lungs in which retained xenon is increased, tissue counts assume less importance.

ASBESTOS-EXPOSED SUBJECTS

In the subjects in group 1, the abnormal gradient of retention of injected xenon recorded after the washout procedure correlated with the observed pathological gradient of lesion density in asbestosis in which the lower zones of the lungs are affected more by fibrosis than the upper (Gough, 1965). This characteristically basal distribution may be causally related to the increased perfusion of dependent lung zones seen in normal upright subjects, as it has been shown that chrysotile fibres increase capillary permeability sufficiently to allow red cell diapedesis into surrounding tissues (Beck *et al.*, 1971). As work in this laboratory (Seaton, 1976) has shown an apical abnormality of xenon washout in asymptomatic cigarette smokers, it is unlikely that the basal defect in this group is related to past tobacco consumption.

It has been demonstrated that impaired washout of xenon gas is a sensitive indicator of small airways obstruction (Evans, 1973). Furthermore, evidence to suggest that the ventilatory abnormality in group 1 might be due to small airways disease is provided by histopathological studies in subjects with asbestosis. These have shown that the early lesions occur around the respiratory bronchioles (Wagner, 1965) where a significant obstruction to flow might be produced in the absence of large airways obstruction (Mead, 1970). Moreover, a study of lung mechanics in asbestos miners showed that the more heavily exposed workers had lower maximal expiratory flow rates for given transpleural pressures, indicating increased upstream airways resistance (Jodoin *et al.*, 1971). It is possible that the increased lung elastic recoil associated with pulmonary fibrosis may also have played a part in impairing washout of xenon in group 1 subjects.

Group 2 did not follow the trend of impaired basal washout of xenon seen in group 1. It might be inferred from this that the impaired lower zone washout in asbestosis is due primarily to lung parenchymal disease and not to coincidental pleural fibrosis, and that pleural calcification alone in the absence of radiological evidence of lung fibrosis is insufficient to disturb regional ventilation as assessed by this technique.

It should be noted that these results indicate relative impairment of lung function in certain regions without necessarily excluding disease in other parts. Thus some subjects in both groups may have had a degree of radiologically undetectable apical emphysema associated with past tobacco consumption (Anderson and Foraker, 1973), sufficient to disturb upper zone washout of xenon. This could account for the trend observed in group 2. In group 1, any similar trend may have been masked by the extent of predominantly basal asbestosis.

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