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Ventilatory Capacity and Lung Volumes of US Coal Miners

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Between 1969 and 1971 the lung volumes and ventilatory capacity of 9,076 US coal miners were determined. In miners with simple coal workers' pneumoconiosis, no relationship existed between ventilatory capacity and radiographic category. However, complicated pneumoconiosis led to definite ventilatory impairment. In contrast, residual volume showed a slight increase with increasing radiographic category of simple pneumoconiosis.

Significant geographic variations in ventilatory capacity and lung volumes occurred that appeared to be related, partly to the type of coal dust to which the miners were exposed, partly to the ethnic origin of the miners, and partly to other miscellaneous nonoccupational factors.

While the occupation of coal mining may, in certain instances, lead to very minor reductions of ventilatory capacity, such reductions are minimal in the absence of complicated pneumoconiosis and would not be associated with respiratory disability.

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The effects of coal dust upon lung functions are still the subject of debate. Numerous studies have shown that simple coal workers' pneumoconiosis (CWP) produces little in the way of a reduction in ventilatory capacity, and indeed that airways obstruction is found with the same frequency in nonpneumoconiotic miners as it is in those who have radiographic evidence of the disease.[1-5] Nevertheless, some studies have shown that coal miners, as a whole, have a greater prevalence of cough and sputum and of ventilatory impairment than does a comparable population of nonminers.[3,6] In other studies such differences were not nearly so apparent.[7]

It has been suggested that the disparate findings may be attributable to the various geographic locations of the studies, and that the environmental conditions that are responsible for the greater prevalence of bronchitis and the lesser ventilatory capacity vary according to the location of the coal mine.[1,8] During the past several years the Public Health Service has been involved in a study of the respiratory status of a large sample of working US coal miners. The data collected in this study allow most of the above hypotheses to be tested and provide an overall indication of the prevalence and magnitude of ventilatory impairment in working US coal miners.

Materials and Methods

In 1969, the Public Health Service and the Bureau of Mines started a nationwide study of the respiratory status of working US coal miners. Thirty-one mines in ten states were selected for inclusion in the study. Of these, 29 were bituminous and two were anthracite mines. Eight were located in Pennsylvania (two anthracite and six bituminous), nine in West Virginia, three in Kentucky, two each in Virginia, Alabama, Illinois, and Utah, and one each in Ohio, Indiana, and Colorado. The mines were chosen to represent different coal seams and different mining methods. Other criteria for selection were a working force of at least 100 miners, expected continued coal production for at least another ten years, and preferably some earlier dust measurements.

Each miner employed at the 31 mines were asked voluntarily to undergo, at no charge to him, a medical examination consisting of standard posteroanterior and left lateral chest roentgenograms and some simple tests of ventilatory capacity. The latter consisted of three forced expiratory volume maneuvers recorded as flow volume loops. Two practice attempts were performed first but were discarded.

A waterless high-fidelity spirometer (Ohio Medical Products, Madison, Wis, Model No. 800) equipped with an air temperature probe (Yellow Spring Model 405) was used. The spirometer has an internal calibrator that produces electrical voltages proportional to flow and volume. These are periodically checked by the use of a calibrated 1,000 ml plastic syringe and by constant flows over the range from 0 to 10 liters per second using a calibrated manometer (Vol-O-Flow, National Instrument Laboratories). The electrical calibrators have been found to be stable during several months of continuous operation. An electronic pulse generator was used to superimpose timing marks on the flow volume loop to permit measurement of the timed lung volumes.[9] Flow volume loops of forced vital capacity (FVC) maneuvers were recorded on a storage oscilloscope (Tektronics Model 564) and the loops were photographed with an attached camera (Polaroid C12). Measurements were made from the photographs and the highest of the three was accepted as the observed value. The values were converted to body temperature, pressure, saturation (BTPS).

The total lung capacity (TLC) of each miner was determined by the radiographic method of Barnhard et al.[10] The largest observed FVC was then subtracted from the TLC to obtain residual volume (RV). Previous studies have shown this to be an acceptable method that can be used in the presence of simple CWP.[11] In complicated pneumoconiosis in which there is extensive radiographic opacification, the method is far less reliable.

In addition, a slightly modified version of the British Medical Research Council's questionnaire on chronic bronchitis was administered and a detailed occupational history was taken.[12]

All roentgenograms were independently interpreted according to the UICC Classification[13] by a panel consisting of Dr. George Jacobson, Professor and Head, Department of Radiology, University of Southern California; Dr. Eugene P. Pendergrass, Emeritus Professor of Radiology, University of Pennsylvania; and one of us (W. K. Morgan). If there was a majority in regard to the major category (0,1,2,3, simple, and A, B, and C complicated pneumoconiosis), namely, either all three or two out of three were in agreement, the majority opinion was accepted. If all three disagreed, a happening that occurred about 10% of the time, the opinion of a fourth reader was solicited. In the exceedingly rare instance where a simple majority was still not achieved (<.2%), a fifth reader was employed.

Normal values for FEV_1 and FVC were those of Kory et al.[14] The subjects were divided into those with and without obstructive airways disease according to whether their FEV_1/FVC was less than or greater than 70%. This definition of airways obstruction was employed because it has been commonly used in epidemiological studies and is applicable in a survey situation.

A multiple covariance technique was used in analyzing the data across the prime factors, eg, radiographic category, geographic region, and years underground, thereby adjusting the means of the various indexes for age and height. Prior work has confirmed that these two variables have significant influence on ventilatory capacity, hence they were the covariates in the statistical model. Moreover, an appropriate multiple range test was used as a means of determining where significant differences occurred. The 95% confidence level was the critical cutoff point in testing.

In order to compare the effects of the miners' working and nonworking environment on ventilatory function, the population studied was divided according to the geographic area in which it was located and according to the type of coal that it mined. A previous study suggested that Pennsylvania anthracite and bituminous miners differ in regard both to the frequency with which symptoms of bronchitis are present and to the prevalence of airways obstruction.[15] Thus, the population was first divided into anthracite and bituminous miners. The latter were then subdivided further into three main groups according to the major region in which they worked, namely, Appalachia, Midwest, and far West.

In a few instances, certain of the major subgroups were broken down still further. Thus, Appalachia was subdivided into northern Appalachia (Pennsylvania, northern West Virginia, and eastern Ohio), and southern Appalachia (southern West Virginia, eastern Kentucky, and Virginia) and Alabama. These further subdivisions were effected because it has been shown that the prevalence of CWP differs greatly in northern and southern Appalachia.[16] Alabama was considered separately because the proportion of Negro miners in this state is approximately 30% to 40%. Elsewhere the figure is well below 10%.

The first round of examinations was completed by July 1971. Participation was 90.5% and 9,076 miners were fully examined. Unfortunately dust measurements are not available since the Bureau of Mines has environmental data of this type dating back only to 1970.

Results

Ventilatory Capacity: Comparison With Predicted Values.—Since it is often impossible to obtain adequate control groups to compare with the coal mining population, the ventilatory capacity of the miners in this study was compared to the predicted figures of Kory et al.[14] Figure 1 shows the mean observed and predicted FEV_1 and FVC for the anthracite and bituminous miners. It is apparent that in the case of the anthracite miners, there is a greater disparity between the observed and predicted figures. Indeed the mean observed FVC of the bituminous miners is slightly, though not significantly, greater than the predicted value. Figures 2 and 3 show the mean observed and predicted FEV_1 and FVC according to region. For most regions, the mean FEV_1 is lower than the predicted figure. An obvious exception is present in the case of miners from the far West (The difference between the observed and predicted FEV_1 is relatively minor except in the eastern

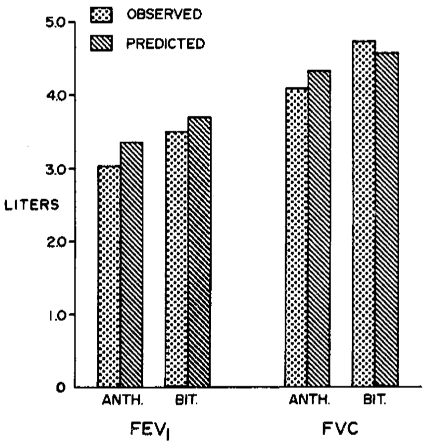


Fig 1.—Ventilatory capacity of anthracite and bituminous miners.

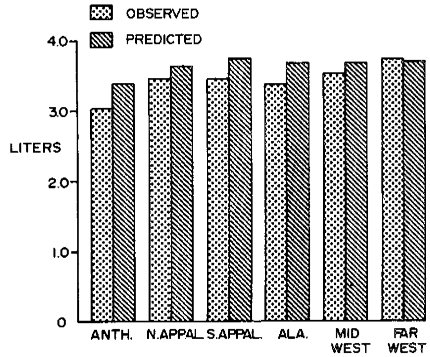


Fig 2.—The FEV_1, observed and predicted, for the various regions.

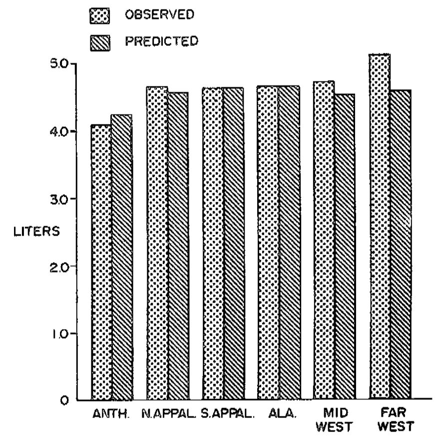


Fig 3.—The FVC, observed and predicted, for the various regions.

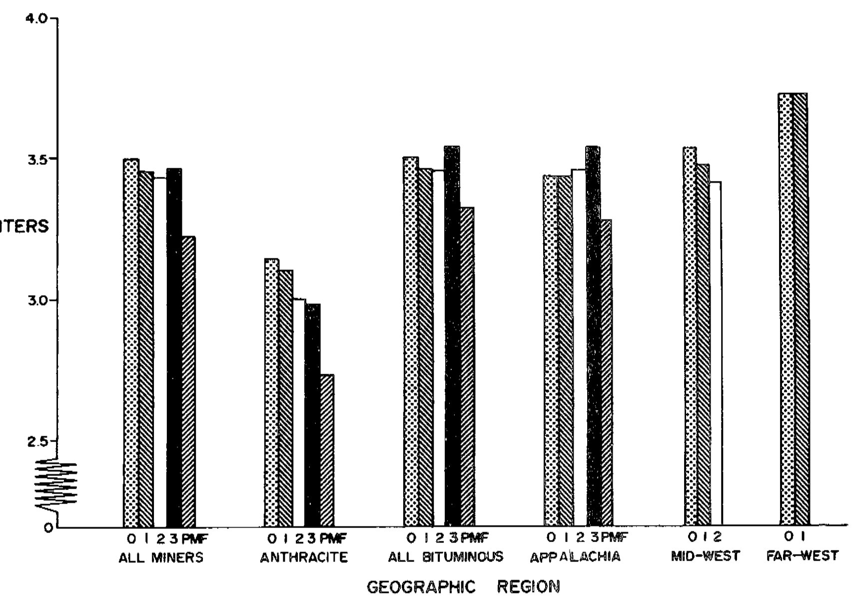


Fig 4.—Mean FEV_1 for each radiographic category according to region.

Pennsylvania anthracite, southern Appalachian, and Alabama miners where the reduction is significant and somewhat more substantial.) Although the subjects used by Kory and his colleagues for deriving their predicted values included a few blacks, no allowance was made for ethnic differences. There is little doubt that Kory's predicted values should not be applied to black subjects, and since a high proportion of the Alabama miners was black, this explains the relatively lower ventilatory capacity found in this group.

These variations in ventilatory capacity cannot be accounted for by differing smoking habits, and indeed the anthracite miners smoke the least of any of the groups. The greater prevalence of progressive massive fibrosis (PMF) is partly responsible for the low mean FEV_1 of the anthracite miners, but, as will become evident later, this accounts for only a minor part of the difference. The mean observed and predicted FVC for the regions resemble each other closely with the obvious exceptions of the anthracite region where the observed figure is lower, and the far West where the observed figure exceeds the predicted.

Relationship of Ventilatory Capacity of Radiographic Category.—The relationship of radiographic category to the various indexes of pulmonary function is shown in the Table. No matter whether the mining population is considered in its entirety, broken down into bituminous and anthracite miners, or subdivided still further, increasing category of simple pneumoconiosis is not associated with a significant decline in FEV_1 (Fig 4). Although the anthracite miners tend to show a decline in FEV_1 with increasing category, in no instances are any of the decrements significant. In contrast, in almost all the miners, regardless of their geographic origin, the onset of complicated pneumoconiosis is associated with a substantial and significant decline in FEV_1.

In regard to FVC, in both the entire sample and in the bituminous miners, there is a slight decline with the change from no pneumoconiosis to category 1. The transition from category 1 to category 2 is associated with a significant reduction in FVC in the complete study population but not in either of the two major subgroups, namely, anthracite and bituminous (Fig 5). Such differences, although just reaching statistical significance, cannot be regarded as clinically important. Otherwise, further increases in category of simple pneumoconiosis are unrelated to changes in FVC. The relationship of $(FEV_1/FVC)\%$ to radiographic category is shown in Fig 6. The differences are all minimal except for PMF.

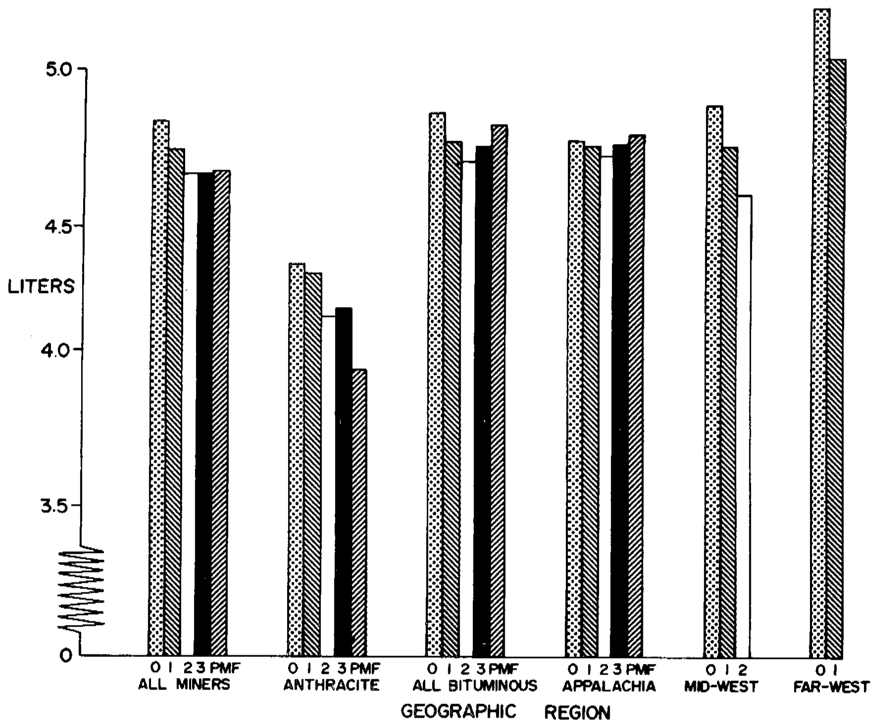
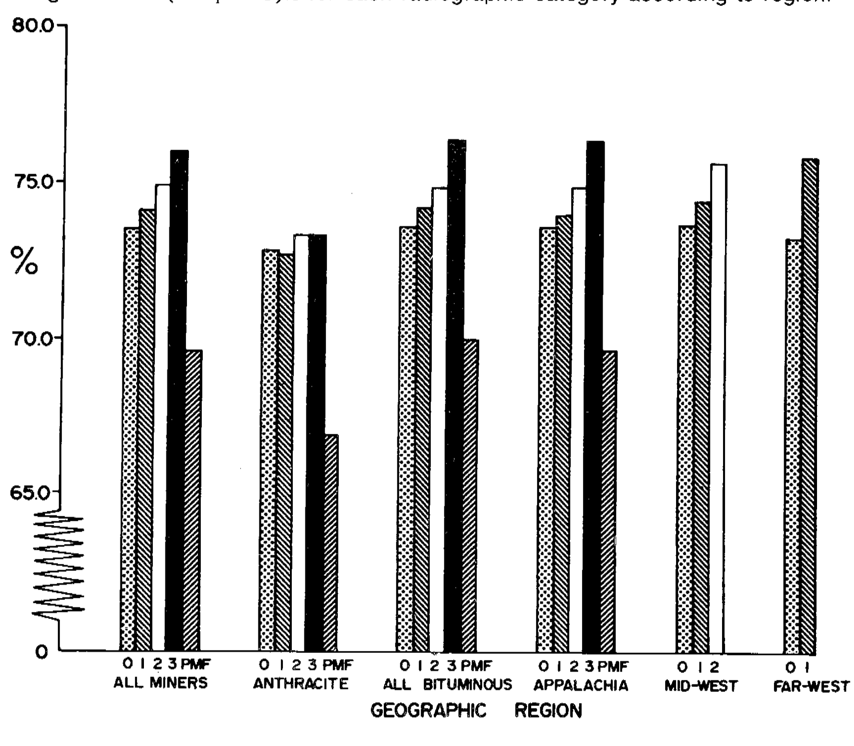


Fig 5.—Mean FVC for each radiographic category according to region.

Fig 6.—Mean (FEV_1/FVC)% for each radiographic category according to region.



As far as the mean (FEV_1/FVC)% in miners with either simple pneumoconiosis or no pneumoconiosis is concerned, none of the subgroups differ from any other by as much as 5%.

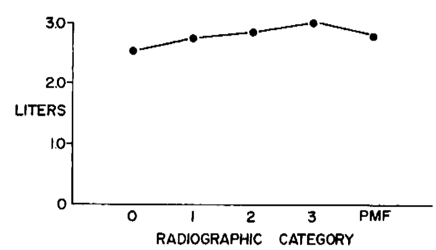
When all the miners are considered, the TLC shows a slight increase from category 0 to category 1 (Table). While this is true of the bituminous miners, it is not of anthracite miners (Table).

The RV shows an increment with increasing category for the entire population (Fig 7). The increase is significant between categories 0 and 1, 1 and 2, but not between 2 and 3, probably because there were relatively few subjects with category 3. Similar findings are present in regard to the (RV/TLC)%. If the bituminous and anthracite miners are considered separately, for both groups there is a difference in RV between categories 0 and 1 but not between any of the categories of simple CWP. Again a similar trend for (RV/TLC)% is present.

Although RV appears to increase with increasing category, differing degrees of obstruction or differing smoking habits may have been present in the different categories of simple CWP, and thus could account for the differences in mean RV. Figure 8 shows the differences in the mean RV of the bituminous miners according to smoking status and obstruction. The apparent anomaly of the obstructed nonsmokers having a higher RV than the obstructed smokers is related to the small number of nonsmoking subjects with obstruction and to the fact that over 50% of them had a history of asthma.

The findings in the anthracite miners were very similar. The upward

Fig 7.—Relationship of RV to radiographic category. All miners.



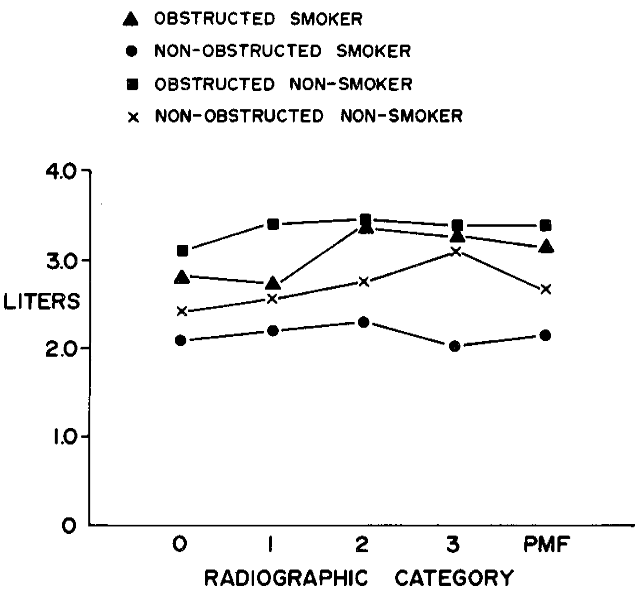


Fig 8.—Relationship of RV to radiographic category, obstruction, and smoking status in bituminous miners.

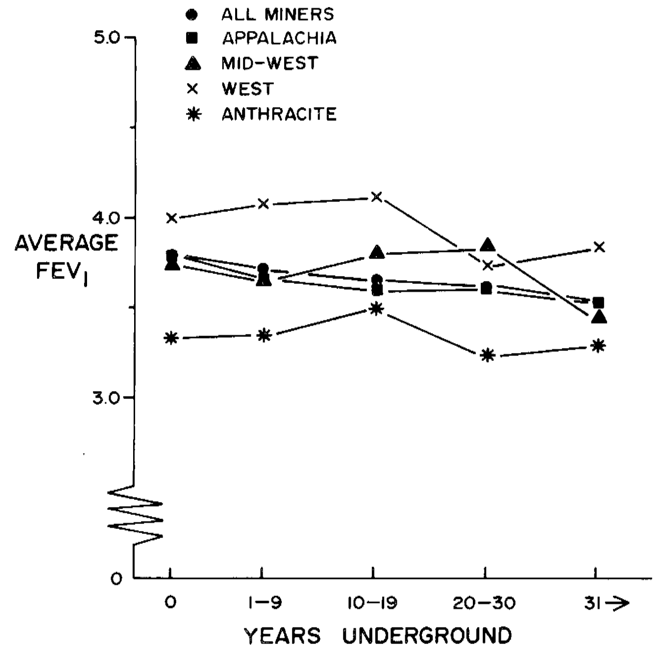


Fig 9.—Relationship of FEV_1 to years underground (nonsmokers).

trend in RV is especially apparent in the nonobstructed nonsmokers; a group that is free of the influences of obstruction and cigarette smoking. The increment in RV with increasing category is more obvious and clearly defined in this subgroup than in any of the other subgroups. In some instances the increases are statistically significant; in others, not. For example, for the anthracite miners, those with category 0 have a significantly lower RV than those with category 1. The fact that in the anthracite miners no other statistically supported differences occurred with increasing radiographic category is thought to be a function of small numbers. For these same radiographic subgroups of bituminous miners, the trend is much more distinct; the RV of those with category 0 being significantly lower than those with any category of simple CWP. It is also apparent that smoking and airways obstruction tend to mask the effects of radiographic category on RV and that obstruction, as defined by the ratio of FEV_1/FVC, has a greater effect than does cigarette smoking. In this regard, it is realized that in smokers, small airways obstruction may be present despite normal spirometry.

Relationship of Ventilatory Capacity to Years Underground.—The effect on ventilatory capacity and lung volumes of dust exposure as measured by years underground is now examined. Since it is known that complicated pneumoconiosis leads to a reduction in ventilatory capacity, and since this condition is seen predominately in older miners with long dust exposures, subjects with this condition were excluded from the analysis. To eliminate the effects of cigarette smoking, only nonsmokers were considered.

The relationship between years underground and FEV_1 is shown in Fig 9. Each mean value has been adjusted for age and height. Although decrements occur that appear to be related to increasing exposure as measured by years underground, no consistent trend occurs throughout all geographic regions. The same exists in regard to the FVC. In the Appalachian miners there is a slight but statistically significant decrement in FEV_1 that occurs between 10 and 19 years underground but is not apparent afterwards. In the western and anthracite groups, a minimal but statistically significant decline occurs

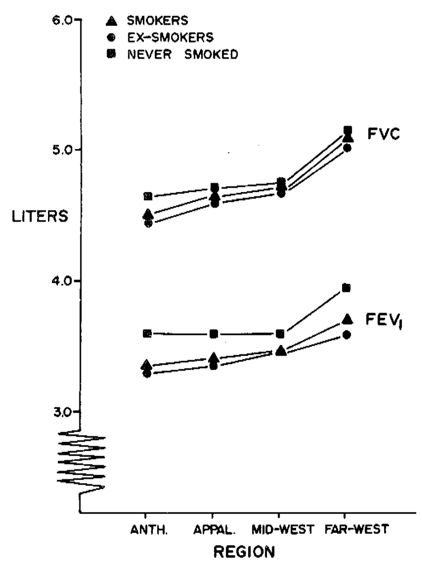
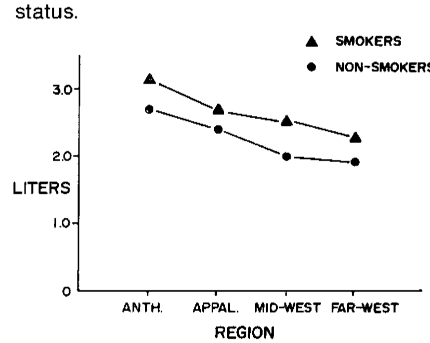


Fig 10.—Relationship of FVC and FEV_1 to geographic region and smoking status.

Fig 11.—Relationship of RV to smoking status.



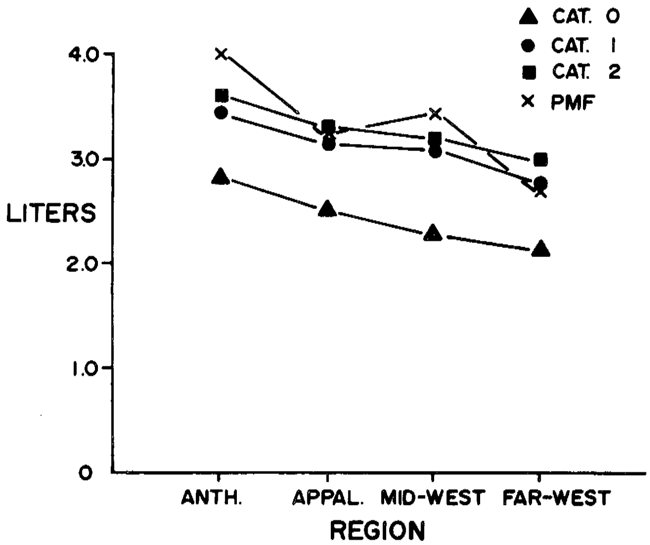


Fig 12.—Relationship of RV to radiographic category in smokers.

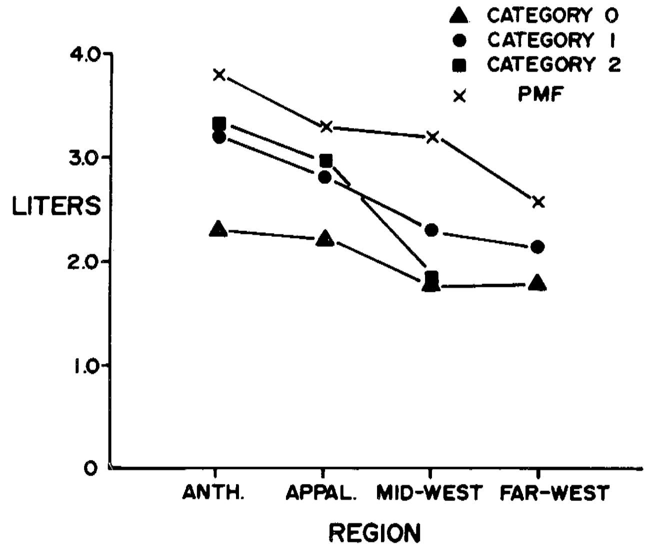


Fig 13.—Relationship of RV to radiographic category in nonsmokers.

between 20 and 30 years of underground exposure. In the Midwest, the FEV_1 declines only after 30 years or more underground. Although small but significant decrements occur in several of the regions, the time of their onset differs. The declines in FVC and FEV_1 range respectively from 150 and 130 ml in Appalachia to 400 and 350 ml in the West. Years underground had no effect on the $(FEV_1/FVC)\%$.

In regard to RV, again there is a slight but statistically significant increase in RV with years underground, but this is probably an effect of increasing radiographic category rather than years underground per se.

It therefore seems that the number of years worked underground may, in certain circumstances, have a slight but statistically significant effect on ventilatory capacity. However, the effect is not seen in all regions and the decrements occur at different durations of dust exposure in different regions.

Relationship of Ventilatory Capacity to Geographic Region.—The mean figures, adjusted for age and height for the various pulmonary function tests across radiographic category within region are represented in Fig 4 to 6. Although we realize that it is not theoretically acceptable to draw inferences across regions within radiographic category (ie, the adjustment of the means negates such comparisons) in this case, the disparities are so marked that it can be assumed that they are real.

It is obvious that wide regional variations exist. Anthracite miners have a lower ventilatory capacity than do their bituminous counterparts. The further West one goes, the better the ventilatory capacity. Such disparities cannot be entirely accounted for by different smoking habits. When the smoking habits for each major region are taken into consideration, the FEV_1 and FVC for each region are again shown in Fig 10. Although there is little difference between the anthracite miners of eastern Pennsylvania and bituminous miners of Appalachia and Midwest, the far Western miners have a significantly larger mean FEV_1 and FVC regardless of their smoking habits. If the mean $(FEV_1/FVC)\%$ for each region is considered, the anthracite miners appear slightly worse off despite the fact that their cigarette consumption has been and is, currently less. Among the bituminous miners the $(FEV_1/FVC)\%$ does not vary significantly between regions (Fig 6).

The mean TLC, RV, and (RV/TLC)% for each region varied markedly. These indexes were most elevated in the anthracite miners and there was a general decline from East to West, with the Utah and Colorado miners having the lowest values.

The roles of the various factors that are likely to account for the regional differences are examined and defined in Fig 11 to 13. There is little doubt that a difference of RV exists across regions. The trend is distinct and statistically significant for both the smokers and nonsmokers (Fig 11). This is not to imply that smoking has no effect, only that its effects cannot entirely account for the regional differences of RV. In this regard, a departure from the general trend does exist for the nonsmokers between the Midwest and far Western regions.

Figures 12 and 13 show the relationship between RV and region for each major radiographic category for smokers and nonsmokers. It is apparent that the original trend persists although it is somewhat less distinct than in Fig 11. Thus, it would seem that regardless of radiographic category or smoking habits, RV appears to be influenced by the region in which the coal miner works, namely, there may be qualitative as well as quantitative effects of the inhalation of coal dust.

Comment

Several studies have shown that coal miners have a greater prevalence of respiratory disease than does the general population.[6,17,19,20] The exact causes of this increased morbidity and mortality are still the subject of debate, and cannot be attributed to a single respiratory disease or to any particular set of circumstances that a coal miner encounters in his job. In some instances, namely CWP, there is a direct relationship between the inhalation of coal dust and the disease that results. Simple CWP, despite its association with several respiratory impairments,[21] does not appear to lead either to premature death or to respiratory disability.[22] In contrast, complicated pneumoconiosis or PMF, has been shown to be associated with a lowered life expectancy.[22] The most common respiratory diseases leading to death in miners are nonspecific obstructive airways disease and lung cancer.[19,22,23] While there is little to suggest that lung cancer occurs more frequently in miners, there are a number of studies that have shown that miners have more bronchitis and a lower ventilatory capacity than do nonminers.[5,19,20] On the other hand, other studies have not shown any difference between coal miners and the general population.[6,7] These disparities might well be related to the geographic area in which the coal mine is situated and perhaps also to the quality and quantity of coal mine dust to which the miner is exposed.

Relationship of Various Indexes of Pulmonary Function to Radiographic Category (Adjusted for Age and Height)

	Radiographic Category				
	0	1	2	3	PMF
			All Miners		
FEV_1 (L)	3.49	3.45	3.43	3.46	3.22
FVC (L)	4.74	4.65	4.57	4.57	4.58
(FEV_1/FVC) %	73.50	74.10	74.90	76.00	69.60
TLC (L)	7.30	7.39	7.41	7.60	7.46
RV (L)	2.56	2.74	2.84	3.02	2.88
(RV/TLC) %	34.10	36.10	37.40	38.50	37.70
Sample size	6,323	1,903	509	56	236
			Anthracite Miners		
FEV_1 (L)	3.14	3.10	3.02	3.01	2.67
FVC (L)	4.28	4.25	4.11	4.14	3.94
(FEV_1/FVC) %	72.80	72.70	73.30	73.30	66.90
TLC (L)	7.58	7.65	7.56	7.70	7.61
RV (L)	3.29	3.40	3.46	3.57	3.67
(RV/TLC) %	42.90	44.00	45.10	46.00	47.50
Sample size	207	120	93	23	75
			Bituminous Miners		
FEV_1 (L)	3.51	3.47	3.46	3.55	3.33
FVC (L)	4.76	4.67	4.61	4.66	4.73
(FEV_1/FVC) %	73.60	74.20	74.90	76.40	70.00
TLC (L)	7.29	7.38	7.39	7.55	7.41
RV (L)	2.53	2.70	2.77	2.89	2.69
(RV/TLC) %	33.60	35.70	36.60	36.80	35.40
Sample size	6,116	1,783	416	33	161

If it is assumed that miners have a lower ventilatory capacity than does a control population, this could be a direct consequence of the inhalation of coal dust particles in the respirable range, ie, those that are responsible for the development of CWP. Were this assumption true, then there should be a decline in ventilatory capacity with increasing radiographic category of simple CWP. Except for a nonsignificant trend in the case of anthracite miners, no such relationship is apparent. It therefore seems likely that the decline in ventilatory capacity is a result of airways obstruction and is unrelated to the presence of radiographic evidence of simple CWP. Similarly, time spent underground has a slight effect on ventilatory capacity only in certain regions but overall appears to be inconsequential. While it must be conceded that cigarette smoking is preeminent in the pathogenesis of obstructive airways disease in coal miners, there is some evidence that a form of industrial bronchitis exists and that the latter is related to the amount of dust to which the miner is exposed.[24] It also seems probable that the chemical and physical composition of the dust might influence the prevalence of airways obstruction.

The present study shows that the mean FEV_1 and FVC of miners for certain geographic regions are substantially lower than they are in others. These differences cannot be accounted for by different smoking habits. In fact, in some regions, when the smoking habits are considered, the ventilatory capacity appears to be inversely related to the prevalence of cigarette smoking. For example, 48% of the anthracite workers in this study were smokers while the percentages in Appalachia, the Midwest, and the West were 54%, 59%, and 49%, respectively. However, other nonoccupationally related factors provide a ready explanation, namely, ethnic background, physical activity, and altitude.[25,26] Differential migration may also play a role in accounting for some of the regional differences. It is possible that the higher values in Colorado and Utah might be partly due to an influx of men with good pulmonary function. To establish that these other factors do not account for the differences would mean that a control population would have to be sought for each region. This is not even possible in many areas, since coal mining is the only occupation in certain regions of Appalachia and elsewhere. Weighing against the likelihood that nonindustrial factors are responsible are the differences that exist in ventilatory capacity between miners from northern and southern West Virginia, and between miners from central and western Pennsylvania. The ethnic origins and nonworking environments of miners from central and western Pennsylvania are very similar. Moreover, Enterline's study of the mining and nonmining population of two towns in southern West

Virginia showed that the ventilatory capacity and the presence of respiratory symptoms of the miners from each town differed significantly.[6] In one such instance there was a small but statistically significant difference between the coal miners and the control population; in the other no such difference existed. It is, therefore, felt that a substantial proportion of the regional differences in ventilatory capacity that have been shown are probably related to the miner's working environment, namely, there are qualitative as well as quantitative effects of the dust to which he is exposed.

If one considers the extent of the ventilatory impairment of the miners included in this study, it is apparent from the comparisons of observed to predicted figures that, with the exception of anthracite miners, such impairment is either minor or minimal. By itself it would not lead to respiratory disability and neither would it affect a miner's working capacity. The prevalence and severity of airways obstruction does not seem to differ much between regions except in the case of the anthracite miners who have somewhat more.

As far as lung volumes are concerned, again interesting regional differences exist, in particular in respect to TLC and RV. The differences are much more marked for RV than TLC and the anthracite miners exhibit the greatest changes. Moreover, RV and to a lesser extent TLC definitely increase with increasing radiographic category. These findings confirm previous observations on Pennsylvania miners.[27] In not all instances is the increase between categories significant. However, the trend is fairly constant except when the numbers of miners are small, eg, Western and far Western miners with categories 2, 3, and PMF. The cause of this increase in residual volume is not certain, but, it has been suggested that it is either a consequence of small airways obstruction or of focal emphysema.[27] No matter which mechanism is responsible, such an increase by itself has little if any clinical importance as far as respiratory disability is concerned.

Mention of brand names or products does not constitute endorsement by the Public Health Service.

References

1. Cochrane AL, Higgins ITT: Pulmonary ventilatory functions of coal miners in various areas in relation to the x-ray category of pneumoconiosis. *Br J Prev Soc Med* 15:1-11, 1961.
2. Rogan JM, et al: Pneumoconiosis and respiratory symptoms in miners at eight collieries. *Br Med J* 1:1337-1342, 1961.
3. Higgins ITT, Oldham PD: Ventilatory capacity in miners: A five-year follow-up study. *Br J Ind Med* 19:65-76, 1962.
4. Hyatt RE, Kistin AD, Mahan TK: Respiratory disease in Southern West Virginia coal miners. *Am Rev Respir Dis* 89:387-401, 1964.
5. Lainhart WS, et al: *Pneumoconiosis in Appalachian Bituminous Coal Miners.* Washington, DC, 1969.
6. Enterline P: The effects of occupation on chronic respiratory disease. *Arch Environ Health* 14:189-200, 1967.
7. Higgins ITT, et al: Chronic respiratory disease in mining communities in Marion County, West Virginia. *Br J Ind Med* 25:165-175, 1968.
8. Ashford JR, et al: The pulmonary ventilatory function of coal miners in the United Kingdom. *Am Rev Respir Dis* 97:810-826, 1968.
9. Hankinson JL, Lapp NL: Time-pulse generator for flow-volume curve. *J Appl Physiol* 29:109-110, 1970.
10. Barnhard HJ, et al: Roentgenographic determination of total lung capacity. *Am J Med* 28:51-60, 1960.
11. O'Shea, J, et al: Determination of lung volumes from chest films. *Thorax* 25:544-549, 1970.
12. Medical Research Council's Committee on the Aetiology of Chronic Bronchitis: Standardized questionnaires on respiratory symptoms. *Br Med J* 2:1665, 1960.
13. Cooperative study by UICC Committee: UICC/Cincinnati classification of radiographic appearances of pneumoconioses. *Chest* 58:57-67, 1970.
14. Kory RC, Callahan R, Boren HG: Clinical spirometry in normal men. *Am J Med* 30:243-258, 1961.
15. Morgan WKC, et al: A comparison of the prevalence of coal workers' pneumoconiosis and respiratory impairment in Pennsylvania bituminous and anthracite miners. *Ann NY Acad Sci* 200:252-259, 1972.
16. Morgan WKC: The prevalence of coal workers' pneumoconiosis. *Am Rev Respir Dis* 98:306-310, 1968.
17. Lapp NL, et al: Lung volumes and flow rates in black and white subjects, *Thorax*, to be published.
18. Carpenter RB, et al: The relationship between ventilatory capacity and simple pneumoconiosis in coal workers: The effect of population selection. *Br J Ind Med* 13:166-176, 1956.
19. Higgins ITT, et al: Respiratory symptoms and pulmonary disability in an industrial town: Survey of a random sample of the population. *Br Med J* 2:904-910, 1956.
20. Higgins ITT: Chronic respiratory disease in mining communities. *Ann NY Acad Sci* 200:197-210, 1972.
21. Morgan WKC, Lapp NL, Seaton A: Respiratory impairment in simple coal workers' pneumoconiosis. *J Occup Med* 14:839-844, 1972.
22. Cochrane AL, et al: The mortality of miners and ex-miners in the Rhondda Fach. *Br J Ind Med* 21:38-45, 1964.
23. Coal mining, pneumoconiosis, and lung cancer, leading article, *Br Med J* 4:502-503, 1967.
24. Kibelstis JA, et al: Prevalence of bronchitis and airway obstruction in American bituminous coal miners. *Am Rev Respir Dis* 108:886-893, 1973.
25. Woolcock AJ, et al: Factors affecting normal values for ventilatory lung function. *Am Rev Respir Dis* 106:692-709, 1972.
26. Ferris BG Jr, Anderson DO, Zickmantel R: Prediction values for screening tests of pulmonary function. *Am Rev Respir Dis* 91:252-261, 1965.
27. Morgan WKC, et al: Hyperinflation of the lungs in coal miners. *Thorax* 26:585-590, 1971.