

EFFECTS OF COAL DUST ON LUNG FUNCTION

Presented by

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With Emphasis on Coal Workers' Pneumoconiosis

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I. Introduction

Over the past five years our laboratory has been engaged in an extensive program of investigation of the effects of coal mine dust on cardiopulmonary function of underground coal miners. We began by studying symptomatic miners in order to see what kinds of impairments existed. Later we employed the dual approach involving a large epidemiological study of working miners for the purpose of gathering both cross-sectional data on prevalence and longitudinal data on progression of pneumoconiosis, respiratory symptoms and airway obstruction, and detailed examination of selected and subsamples in the laboratory.

My presentation of our findings to date will be made according to the type of impairments found and whether they were studied in subjects who were symptomatic or among working miners who were selected more or less randomly.

II. Dynamic Lung Volumes

The subjects for this study were 8,555 working bituminous coal miners who were selected from 29 mines widely scattered throughout the United States. The mines were chosen to represent different mining methods, expected to have a working life of at least ten years, employed at least 100 miners, and as often as possible should have had retrospective dust exposure data available. The 8,555 men comprised 90.8 percent of the men employed at the 29 mines.

The relationship of airway obstruction, as determined by the ratio of observed FEV_{1.0} to predicted FEV_{1.0}, and the miner's job and smoking habits is shown in Table 1. Since the predicted FEV_{1.0} is corrected for age and height of the subject, any changes noted are related to either job (and, hence, dust exposure) or smoking habits. Dust sampling by the U. S. Bureau of Mines has shown that the highest concentrations of respirable dust (0.5 to 5.0 μ particle size) occur in face operations and the lowest at surface operations with intermediate levels for the operations between depending largely upon proximity to the face.

The results show that nonsmoking miners who worked predominantly at the face have significantly more airway obstruction than their counterparts who worked at the surface. The same is true of former smokers within these job categories. On the other hand, among current smokers there was no detectable gradient of increasing airway obstruction from surface to face operations. Within job categories there was significantly more obstruction among smokers and ex-smokers than among nonsmokers for all except maintenance workers. It appears that both coal dust exposure and smoking status affect airway obstruction in working miners.

III. Static Lung Volumes

The residual volume and total lung capacity of 1455 working miners from six mines in central and western Pennsylvania were determined. This group represented a subsample of the previously described cohort and comprised 96 percent of the men working at

these mines. Total lung capacity was determined by the radiological method of Barnhart and associates, and the residual volume was calculated by subtracting the forced vital capacity obtained from a spirometric tracing from the total lung capacity determined by the radiographic method.

The miners were subdivided into six groups according to their radiological category and the presence or absence of airway obstruction, viz.:

1. Non-obstructed subjects without evidence of CWP.
2. Obstructed subjects without evidence of CWP.
3. Non-obstructed subjects with Category 1 CWP.
4. Obstructed subjects with Category 1 CWP.
5. Non-obstructed subjects with Categories 2 and 3 CWP.
6. Obstructed subjects with Categories 2 and 3 CWP.

Subjects with an $FEV_{1.0}/FVC$ ratio of less than 70 percent were considered obstructed; whereas, those with a ratio of greater than 70 percent were considered non-obstructed.

The mean ratio of observed residual volume to predicted residual volume (RV_O/RV_p) expressed as a percentage for each group is shown in Figure 2. It is apparent that the subjects with obstruction have a higher RV_O/RV_p ratio than do those without obstruction. Of more interest is the fact that the non-obstructed subjects with Category 1 and with Categories 2 and 3 have significantly increased RV_O/RV_p when compared to the non-obstructed subjects with no

pneumoconiosis. This seems to indicate that radiological evidence of CWP is associated with an increased residual volume in the absence of obstruction as usually determined. A similar trend of increased RV_0/RV_p with increasing category of CWP was found among the obstructed miners. This cannot be attributed to increasing severity of obstruction since the mean $FEV_{1.0}/FVC$ ratio was virtually the same in all groups. Figure 3 shows the mean observed total lung capacity and predicted total lung capacity for each of the groups. A slight upward trend in observed TLC was noted with increasing radiographic CWP that was significant only for the non-obstructed miners.

When the miners without obstruction were divided into smokers, ex-smokers, and nonsmokers, and the mean RV_0/RV_p for each group was plotted against radiographic category of CWP, there was a constant upward trend noted regardless of smoking habits (Figure 4).

We interpret these findings of hyperinflation in the absence of obstruction in the usual sense, particularly in the nonsmoking miners and relating to increasing category of CWP, as evidence for the presence of either an elevated resistance within small airways or focal emphysema, either of which could be a consequence of dust deposition within the lungs.

IV. Diffusing Capacity

The diffusing capacity for carbon monoxide (D_{LCO}) was determined by the single breath technique in 25 working miners from

three bituminous mines in northern West Virginia and southwestern Pennsylvania. The criteria for selection were:

1. The miner must have been a nonsmoker for at least ten years.
2. He must have Category 2 or 3 simple CWP with the predominant opacity being p or q.
3. He must have an $FEV_{1.0}/FVC$ ratio of 70 percent or greater.
4. He must be free of other cardiorespiratory disease.

Of the 25 chosen, 15 had micronodular (q) opacities, while ten had the pinpoint (p) opacities. The results are shown in Figure 5.

One subject had a D_{ICO} that fell outside the normal range. However, if the mean D_{ICO} for subjects with p opacities is compared with that for the subjects with q opacities a significantly lower value was obtained in the former subjects. This finding confirmed the findings of other workers (Lyons et al, Sartorelli, et al) that the p type of CWP is associated with a slightly lower D_{ICO} than the q type of CWP. The reasons for this difference remain unknown at this time.

V. Gas Exchange

Fifty-One miners who professed respiratory symptoms but had normal spirometry underwent studies of gas exchange. The results are shown in Table 2. Subjects with Categories 0 and 1 CWP showed mean arterial oxygen tensions which were on the lower side of normal but which improved with exercise. The mean value for alveolar-arterial oxygen difference $[(A-a) D_{O_2}]$ was abnormally elevated in

the subjects with Category 0; however, this decreased with exercise into the normal range. The physiological dead space/tidal volume ratio was abnormally elevated at rest in all groups, but returned to normal with exercise, except in the group with Category 3 and in those with complicated CWP. Similarly, the only subjects showing hyperventilation during exercise were those who had either Category 3 or complicated CWP.

VI. Pulmonary Hemodynamics

Cardiac catheterization was carried out in 47 symptomatic coal miners from the Pennsylvania and West Virginia coal mining regions. Of the 47, 24 had airway obstruction as recognized by an FEV_1/FVC of less than 70 percent. Seven of these (Figure 6) had elevation of pulmonary artery pressures which could be accounted for by either obstruction or the presence of complicated pneumoconiosis. Of the 23 without obstruction, many of whom had minor abnormalities of gas exchange (Figure 7), only one had minimal elevation of pulmonary artery pressure at rest. Three others developed elevations of pulmonary artery pressure during exercise. All four of these subjects had the "p" or pinhead type of opacity. Two of the four had considerable exposure to silica as well as coal dust and, in this connection, silicosis is known to lead to occlusive pulmonary vascular disease.

Lung perfusion scanning using macroaggregated human serum albumin tagged with ^{131}I was performed in 37 symptomatic coal

workers. We found areas of absent and decreased perfusion related to areas of conglomerate fibrosis and bullae in all of the 16 subjects with complicated pneumoconiosis, but only minor abnormalities in two out of 21 subjects with simple pneumoconiosis.

VII. Lung Mechanics

Lung mechanical properties were investigated in 62 symptomatic coal miners with normal spirometry. Twenty had Category 0, 23 had Category 1, 14 had Category 2, and 5 had Category 3 chest radiographs. No significant differences in age, years underground, or smoking habits was seen between those with no CWP and those with CWP. Total lung capacity and residual volume tended to be higher than predicted (Table 3); findings that have already been commented upon. No tendency for either a reduced or increased static compliance with increasing category was noted. There did appear to be an increasing prevalence of abnormally low coefficient of retraction (P_{el}/TLC) with increasing category of CWP. Among subjects with complicated CWP the number with elevated coefficient of retraction appeared to increase with stage of pneumoconiosis.

Twenty-five working bituminous coal miners who had at least Category 2 or 3 simple CWP and were either lifelong nonsmokers or had not smoked for at least 10 years underwent detailed lung mechanics studies including measurements of dynamic compliance at frequencies up to 60 breaths per minute. All of these had normal spirometry, lung volumes, airway resistance, static compliance, and pulmonary recoil pressure at TLC. Seventeen of the 25 demonstrated

a significant fall in dynamic compliance at faster respiratory frequencies (Figure 8); whereas, none of six controls of comparable age but with no mining exposure had compliances that fell at similar frequencies. Ten of the 25 miners had symptoms of bronchitis; whereas, 15 had none, yet the presence or absence of bronchitis did not seem to explain the findings of frequency dependence of dynamic compliance. Six of the 10 with bronchitis (Figure 9) showed a fall in compliance at rapid respiratory rates, and 11 of the 15 (Figure 10) nonbronchitic subjects demonstrated this change.

That the phenomenon of frequency dependence of dynamic compliance is a consequence of simple CWP seems apparent from studies just completed among working miners with Category 1 and Category 0 CWP (Table 4). One of 11 subjects with Category 0, and 5 of 17 subjects with Category 1 CWP were shown to demonstrate frequency dependence of compliance.

VIII. Summary

In order to ascertain the chronic effects of coal dust deposition on lung function it is necessary to study a population of miners who have no other concomitant respiratory disease. This situation is best achieved by first excluding subjects with demonstrable disease of the larger airways as manifested by abnormal spirometric findings and, secondly, by using only nonsmoking subjects.

Using this approach, we have demonstrated that subjects with simple CWP may have certain respiratory impairments, namely:

1. That their residual volume is often larger than the predicted value, and that the ratio of observed to predicted RV increases with increasing category of simple CWP.
2. That minor abnormalities of gas exchange are often present. Some increase in the physiological dead space to tidal volume ratio and alveolar to arterial oxygen difference occurs as a consequence of ventilation-perfusion abnormalities.
3. That subjects with the pinhead (p) type of small opacity tend to have a somewhat lower diffusing capacity than do those with the micronodular (q) opacities. Nonetheless, clinically significant reductions in diffusing capacity are rare in our experience when a miner has simple CWP and no other pulmonary disease.
4. That a slightly elevated pulmonary artery pressure is sometimes found.
5. That the mechanical properties of the lungs are occasionally altered. The retractive forces in some miners are somewhat diminished, although they more often remain within normal limits.

6. That a proportion of miners with simple CWP demonstrate a decrease in lung compliance with increasing frequency of respiration. This phenomenon appears to increase in prevalence with increasing category of CWP. It may be a consequence of either an increase in the resistance of upstream peripheral small airways or of unequal time constants owing to the focal emphysema associated with the coal macules.

Table 1.--Mean Observed FEV₁/Pred. FEV₁ percentage according to principal job*

Principal Job	Smokers		Exsmokers		Nonsmokers	
	Total, no.	Mean,* pct.	Total, no.	Mean,* pct.	Total, no.	Mean,* pct.
Face	2046	92.1 ±17.05**	952	93.9 ±18.30**	759	98.1 ±16.33**
Transportation	868	89.8 ±17.64	331	94.2 ±18.90	244	97.9 ±15.12
Maintenance	772	93.0 ±16.45	347	98.0 ±15.62	289	100.0 ±16.93
Miscellaneous	389	92.9 ±15.41	156	96.8 ±15.44	159	101.6 ±15.32
Surface	563	91.8 ±17.07	387	98.1 ±17.07	268	102.4 ±16.17

* Mean $\left(\frac{\text{obs. FEV}_1}{\text{Pred. FEV}_1} \right) \times 100$

* Standard Deviation

Fig. 1

lungs in coal miners

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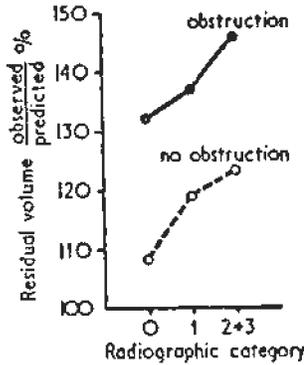


FIG. 1. Relation of Residual volume (obs.) to radiographic category. $\frac{\text{Residual volume (obs.)}}{\text{Residual volume (pred.)}}$

Fig. 2

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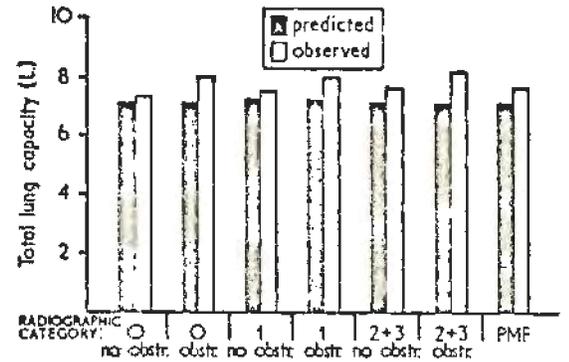


FIG. 2. Mean total lung capacity (B.T.P.S.) of seven groups of miners.

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Figures 3 + 4

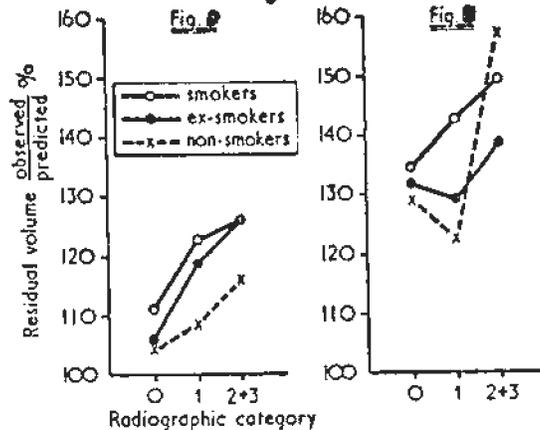


FIG. 3. Relation of Residual volume (obs.) in non-obstructed miners to radiographic category. $\frac{\text{Residual volume (obs.)}}{\text{Residual volume (pred.)}}$

FIG. 4. Relation of Residual volume (obs.) in obstructed miners to radiographic category. $\frac{\text{Residual volume (obs.)}}{\text{Residual volume (pred.)}}$

Figure 5

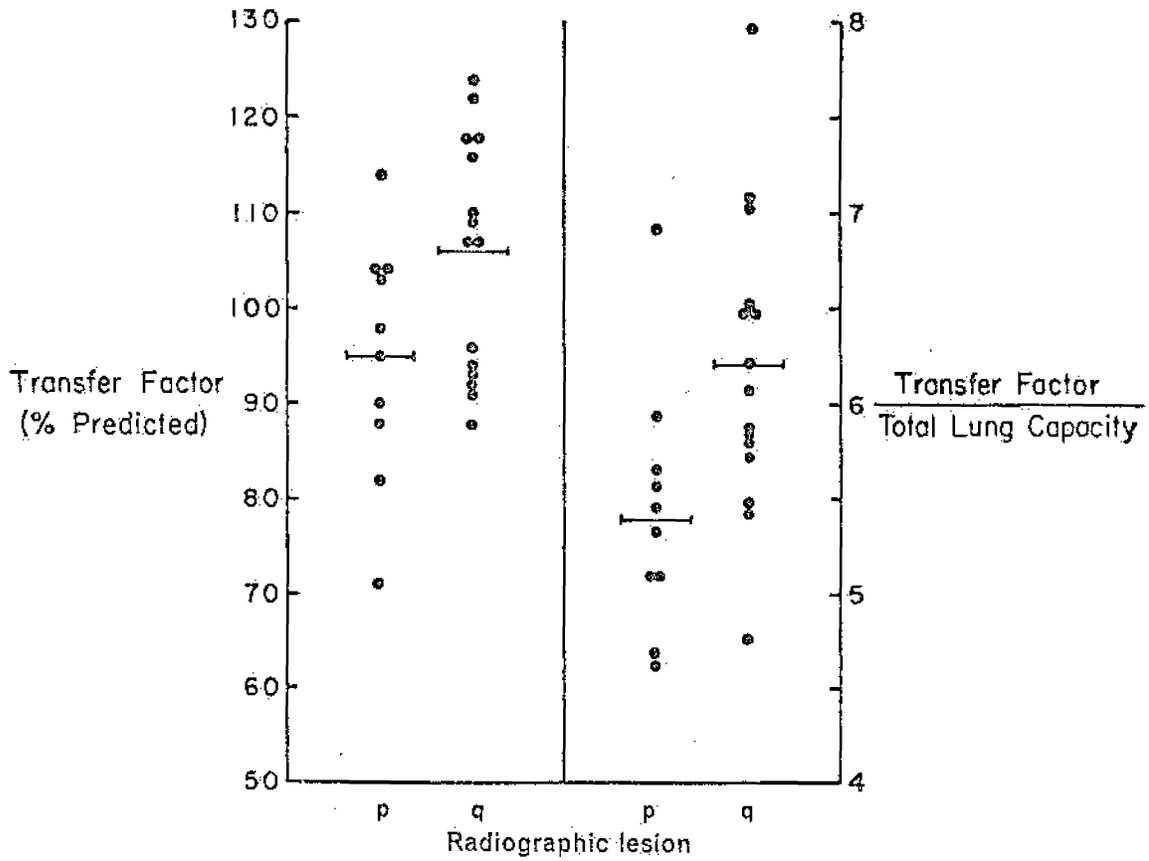


FIGURE Values for transfer factor and transfer factor/total lung capacity in miners with p and q opacities.

TABLE 2

TABLE 2
GAS EXCHANGE IN SUBJECTS WITH SIMPLE CWP

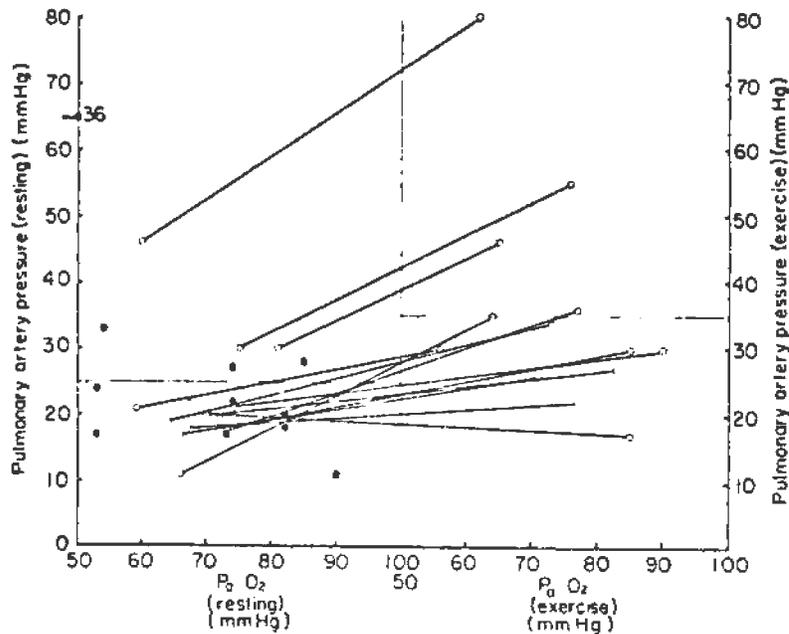
Radio-graphic category	Number of patients	Age	(A-a) O ₂ (mm Hg)		P _a O ₂ (mm Hg)		V _D /V _T		Minute ventilation (L/min/m ²)		Oxygen uptake (L/min/m ²)		
			Rest	Exer.	Rest	Exer.	Rest	Exer.	Rest	Exer.	Rest	Exer.	
0	12	Mean	53	32	25	76	81	0.43	0.35	6.69	19.73	0.158	0.587
		S.D.	(12.2)	(12.8)	(7.8)	(11.1)	(6.5)	(0.10)	(0.15)	(1.40)	(4.76)	(0.027)	(0.168)
1	23	Mean	59	24	24	77	80	0.45	0.35	6.18	19.13	0.156	0.540
		S.D.	(4.9)	(12.3)	(11.9)	(9.5)	(9.1)	(0.12)	(0.09)	(1.54)	(8.21)	(0.034)	(0.171)
2	11	Mean	55	24	30	81	82	0.49	0.37	6.86	20.93	0.152	0.555
		S.D.	(7.4)	(12.4)	(19.4)	(8.4)	(8.5)	(0.08)	(0.11)	(2.41)	(7.09)	(0.040)	(0.327)
3 and A	5	Mean	55	27	30	82	81	0.40	0.40	5.87	27.37	0.134	0.629
		S.D.	(9.5)	(8.6)	(18.1)	(6.1)	(16.7)	(0.06)	(0.14)	(1.61)	(11.60)	(0.018)	(0.152)

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Figure 6

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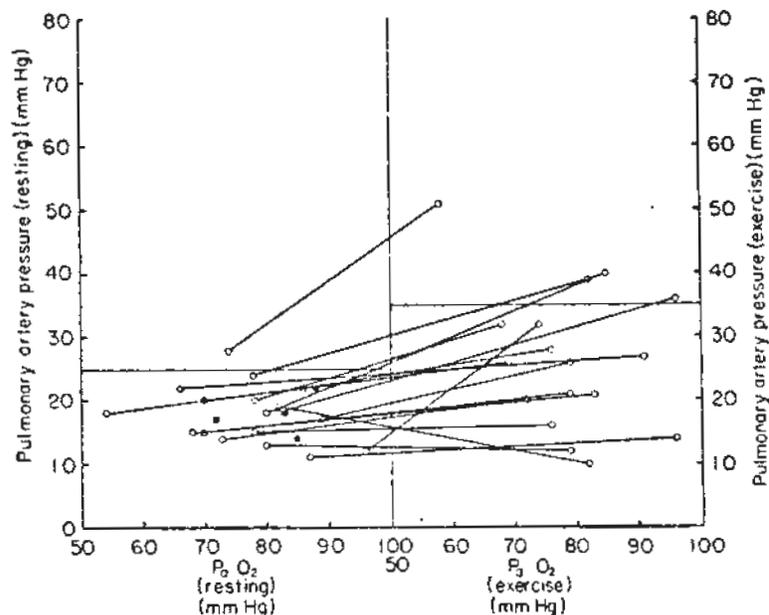


TABLE 3

TABLE 3
Mean Data on Subjects in Group 1A

Radiographic category	Number of subjects		Age	Time underground	Cigarettes	$\frac{FEV_1}{FVC}$	Total lung capacity	Residual volume	$\frac{RV}{TLC}$	Functional residual capacity
0	20	Mean	51	28	19	80	117	134	43	4.8
		SD	9	11	20	7	20	56	13	1.3
1	23	Mean	58	32	15	80	112	114	41	4.1
		SD	7	9	21	5	2.2	43	11	1.1
2	14	Mean	55	30	18	78	112	107	37	4.2
		SD	7	10	16	5	14	34	11	0.9
3	5	Mean	53	32	11	78	115	113	38	4.8
		SD	7	13	15	4	16	50	15	0.8

Figure 8

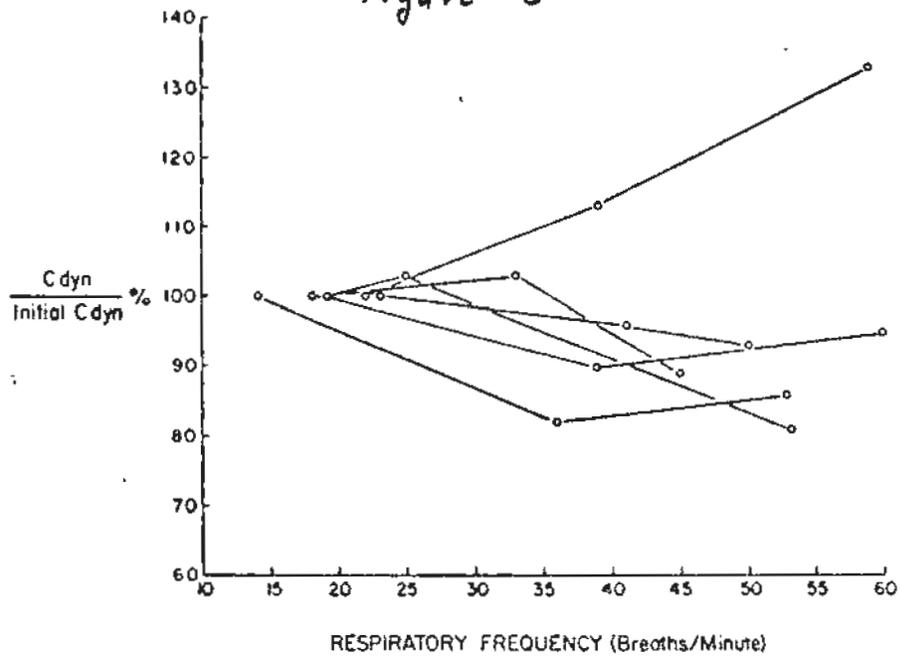


FIGURE 8 Dynamic compliance at different respiratory rates expressed as a percentage of the initial dynamic compliance (normal controls).

Lung Mechanics and Frequency Dependence of Compliance in Coal Miners

Figure 9

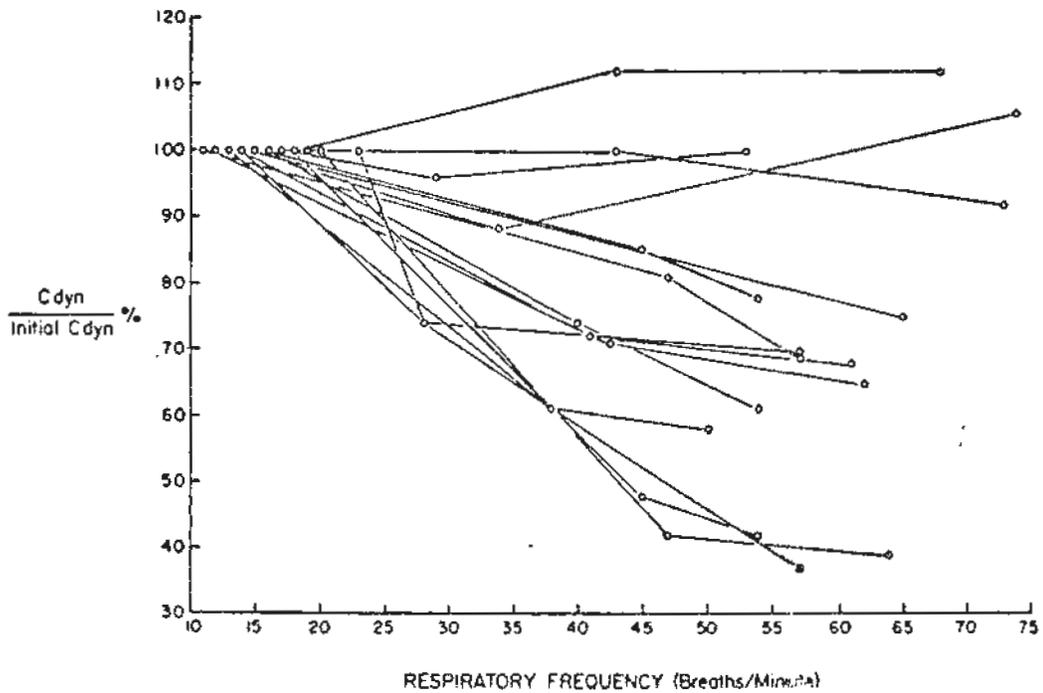


FIGURE 9 Dynamic compliance at different respiratory rates expressed as a percentage of the initial dynamic compliance (working miners, nonbronchitic).

TABLE 4

	<u>No.</u> <u>Subjects</u>	<u>Radiographic</u> <u>Category</u>	<u>Age</u>	<u>Height</u>	<u>FEV</u> <u>1.0</u> <u>% Pred.</u>	<u>No.</u> \downarrow <u>Cdyn.</u>
Controls	7	0	51.3	175.6	110.0	0
Miners	11	0	54.2	174.2	95.4	1
Miners	17	1	52.3	176.1	107.3	5