Diffusing Capacity in Bituminous Coal Miners*

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Pulmonary diffusing capacity (D_L) was measured in 133 underground bituminous coal miners at rest and during moderate exercise by the steady state end tidal sampling method. The average D_L among cigarette smoking miners was lower than among nonsmoking miners of comparable age and years of underground mining. In contrast to the smoking miners, a large majority of nonsmoking miners had normal D_L. This difference in D_L could not be explained by the presence of bronchitis, airway obstruction, or radiographic evidence of coal workers' pneumoconiosis (CWP), although bronchitis and CWP were more frequent among the smoking miners. It is doubtful that the measurement of D_L would be a useful screening test for occupational disease among cigarette smoking coal miners, since it is significantly affected by smoking.

The detection of respiratory impairment in coal miners has been and continues to be the subject of much debate. Most studies of pulmonary function in coal miners in the United States have dealt with retired or active coal miners who have definite radiographic evidence of coal workers' pneumoconiosis (CWP). However, several reports[1,2] have emphasized that respiratory impairment may be present in coal miners without radiographic evidence of dust retention. Yet, such impairment has been inferred to be a consequence of the occupation of coal mining. Rasmussen and his colleagues[2] claim that arterial blood gas studies and diffusing capacity measurements are essential to detect this impairment, and that ventilatory studies alone are inadequate.

Were it possible to demonstrate reduced diffusing capacity in certain coal miners, this might well be due to factors other than coal mining, namely cigarette smoking. Martt[3] and Krumholz,[4] among others, showed a reduced diffusing capacity in cigarette smokers which improved after cessation of smoking. Studies, such as that of Nadel and Comroe,[5] have repeatedly shown adverse effects of smoking on airway conductance and particle clearance. While Naeye, Mahon, and Dellinger[6] found "no influence of smoking on the primary dust macule," they found a greater prevalence of cor pulmonale and bronchitis in bituminous coal miners who smoked than in those who did not.

The current study was undertaken to answer two questions: First, would the routine measurement of D_L be likely to uncover a significant number of miners with respiratory impairment not detectable by the respiratory questionnaire, spirogram, and chest x-ray film currently used in the Interagency Study of Coal Workers' Pneumoconiosis (IAS)? Second, could cigarette smoking account for such impairment, if found?

Methods

Subjects were selected from four large bituminous coal mines located within 65 miles of our laboratory at Morgantown, W. Va. These mines had been surveyed as part of the IAS, and respiratory questionnaires (patterned after the British Medical Research Council respiratory questionnaire), posteroanterior and lateral chest roentgenograms and spirometry were available on more than 80 percent of the 1,826 miners employed. Six groups were selected on the basis of years worked underground and smoking history, as is shown in Table 1. A group of regular cigarette smokers and a group who had never smoked were selected from each of three underground work experience categories, namely those who had worked five years or less (1), those who had worked from six to 15 years (2), and those who had worked from 16 to 25 years (3).

From these lists, 199 men were contacted by telephone or letter and 142 men (71 percent) reported to the laboratory. Nine participants were omitted from statistical computations for the following reasons: two men had retired from mining, one man had worked more than 25 years underground, and six men had stopped smoking.

The 57 miners who did not participate were distributed roughly in proportion to the number of participants in each of the six groups. They did not differ from those who partici-

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Table 1—*Distribution of Participating Miners by Work Experience and Smoking History*

	Smoking History	
Group 1: (5 years or less as underground coal miner)	Smokers 26	Nonsmokers 25
Group 2: (6 to 15 years as underground coal miner)	27	10
Group 3: (16 to 25 years as underground coal miner)	25	20

pated in these six groups in mean age, height, weight, years underground, presence of obstruction, or presence of bronchitis except in Group 2. The nonresponders in this group were younger (39.35 years for smokers and 35.17 years for nonsmokers) and had less underground experience than participants. Fewer nonparticipants had radiographic evidence of CWP than did participants.

Nonsmoking miners with between six and 15 years of underground mining were few in number in the four mines from which the subjects were drawn. Rather than introduce a significant selection bias by seeking participants from other mines, this group was left with only ten men.

Steady state diffusing capacity for carbon monoxide was measured in the erect posture, at rest and during moderate treadmill exercise by the end tidal sampling method of Bates.[7] Oxygen consumption during exercise was an average of 1.6 liters per minute. Results were corrected for back pressure of carbon monoxide and compared to predicted values of Bates as modified by Wilmot Ball.* Total lung capacity and airway resistance were measured in a body plethysmograph by the method of Dubois and his associates.[8] A history of mining experience and smoking status was obtained when the miners visited the laboratory and was in agreement with that obtained for the IAS except for the nine men omitted from statistical analysis.

Table 3—*Diffusing Capacity at Rest in Bituminous Coal Miners

Group No.	Smokers	Nonsmokers	p
1	70.14 ± 14.37	87.68 ± 17.94	<.001
2	72.16 ± 14.15	90.65 ± 22.62	<.01
3	83.23 ± 21.87	98.35 ± 22.94	<.05

*Expressed as mean of percentage of predicted ± one standard deviation.

Results

Table 2 gives a description of the six groups. Table 3 presents the results of diffusing capacity measurements at rest. It shows that a statistically significant difference exists between the smoking and nonsmoking groups with the same work experience. Similar results were found during exercise (Table 4). Not only were the mean values significantly different, but also the numbers of men with resting and exercise D_L's greater than 80 percent of predicted values (and thus considered within normal limits) were also different for smokers and nonsmokers. This is shown in Table 5. Lower values for D_L were found in nonsmoking control subjects between 20 and 29 years of age. Control values

*Rest DL_{CO}=15.9(0.163 height/inches) minus (0.246 age/yrs); exercise DL_{CO}=37.7+(8.75$\dot{V}O_2$STPD) minus (0.53 age/yrs).

Table 2—*Description of Subjects Grouped by Work Experience and Smoking History*

	Group 1		Group 2		Group 3	
	Smokers	Nonsmokers	Smokers	Nonsmokers	Smokers	Nonsmokers
Miners, no.	26	25	27	10	25	20
Age, yrs.*	29.2 ± 5.3	30.5 ± 9.1	41.6 ± 7.6	44.4 ± 8.7	46.1 ± 5.8	47.1 ± 5.5
Underground, yrs.*	2.97 ± 1.68	1.94 ± 1.19	10.5 ± 2.6	11.1 ± 2.9	20.8 ± 2.2	21.2 ± 2.3
Wt., lbs.*	176.6 ± 23.1	189 ± 20.7	169.4 ± 18.7	175.3 ± 26.6	179.5 ± 24.1	189.1 ± 29.5
Ht., in.*	69.1 ± 2.1	69.3 ± 2.0	68.6 ± 1.9	68.0 ± 2.3	68.7 ± 2.5	68.7 ± 2.3
Pack yrs.** smoking*	11.0 ± 8.6	0	22.9 ± 10.1	0	33.4 ± 17.0	0
FEV_1/FVC x 100*	78.4 ± 6.4	79.8 ± 6.5	73.2 ± 10.1	75.5 ± 7.8	75.1 ± 6.2	75.1 ± 8.8
RV/TLC x 100*	29.5 ± 8.9	22.8 ± 9.3	37.1 ± 9.9	33.6 ± 11.3	38.6 ± 8.0	34.6 ± 8.0
(Observed RV) / (Predicted RV) x 100*	95 ± 34.5	90 ± 14	113 ± 39.7	94 ± 31	113 ± 43	109 ± 59
Raw*	1.67 ± 0.70†	1.71 ± .47††	2.19 ± 1.11	1.95 ± 0.54	1.77 ± 0.58	2.22 ± 1.14
$\dot{V}O_2$ on exercise*	1.61 ± 0.30†	1.64 ± 0.36	1.70 ± 0.50	1.43 ± 0.43	1.52 ± 0.39	1.63 ± 0.34
TLC* % predicted	101.2 ± 11.3	96.2 ± 10.6	105.5 ± 15.3	96.5 ± 14.7	104.7 ± 14.0	104.0 ± 14.8
Bronchitic, no.	5	4	9	1	11	2
Surface work, no.	0	0	7	3	5	5
CWP by x-ray film						
Category 1	3	4	8	2	7	2
Category 2	1	0	1	0	4	3
FEV_1/FVC less than predicted, no.	16	13	16	5	15	12

*Mean ± standard deviation. **No. of years times no. of packs per day. †n= 25. ††n = 24.

Table 4—*Diffusing Capacity During Exercise in Bituminous Coal Miners**

Group No.	Smokers	Nonsmokers	p
1	71.49 ± 12.90	85.99 ± 13.62	<.001
2	81.75 ± 19.49	103.28 ± 21.44	<.01
3	89.21 ± 12.65	102.88 ± 19.82	<.01

*Expressed as mean of percentage of predicted ± one standard deviation.

Table 5—*Percentage of Miners in Each Group with D_L at Rest and During Exercise Greater Than 80 Percent of Predicted Values*

Group No.	Smokers, %	Nonsmokers, %
1	12 (3 of 25)	56 (14 of 25)
2	18.5 (5 of 27)	60 (6 of 10)
3	40 (10 of 25)	75 (15 of 20)

were 91.0 ± 15.9 at rest and 89.4 ± 22.4 during exercise for 11 subjects. This reflects a nonlinear relationship of age to D_L in the formula for predicted values.

These differences in D_L between smoking and nonsmoking miners cannot be explained by the presence of bronchitis (persistent cough and phlegm production), radiographic evidence of CWP, or spirometric evidence of airflow obstruction (FEV_1/FVC less than predicted FEV_1/predicted FVC of Kory[9]). As seen in Table 2, the prevalence of bronchitis was significantly higher among miners who had more than five years experience underground and who smoked. However, the diffusing capacity did not differ significantly between bronchitic and nonbronchitic smoking miners (Table 6). A larger sample would be necessary to confirm this finding.

Three groups had five or more men with radiologic evidence of CWP. No statistically significant relationship of D_L with radiographic evidence of CWP was found because of the sample size. The results of this comparison are shown in Table 7.

All six men who had stopped smoking as little as two months prior to testing had normal resting D_L as shown in Table 8. Only one of the five exsmokers who were exercised had a D_L more than 20 percent below predicted levels during exercise.

Table 6—*Effect on Bronchitis on D_L at Rest and During Exercise Among Smoking Miners*

	With Bronchitis	Without Bronchitis	t
Group 2:			
No.	9	18	
Rest*	71.62 ± 13.47	72.41 ± 14.86	−0.134
Exercise*	74.36 ± 9.36	85.45 ± 22.28	−1.82
Group 3:			
No.	11	14	
Rest*	85.44 ± 22.31	77.31 ± 20.31	0.83
Exercise*	93.16 ± 14.78	87.09 ± 10.46	1.20

*Expressed as mean of percentage of predicted ± one standard deviation.

Table 7—*Effect of CWP on Diffusing Capacity in Miners*

	With CWP	Without CWP	t
Group 2 (Smokers)			
No.	8	19	
Rest*	71.03 ± 9.68	72.64 ± 15.87	−0.265
Exercise*	79.89 ± 23.73	82.54 ± 18.09	−0.317
Group 3 (Smokers)			
No.	11	14	
Rest*	84.1 ± 24.63	78.36 ± 18.56	0.654
Exercise*	94.52 ± 16.24	86.03 ± 7.61	1.65
Group 3 (Nonsmokers)			
No.	5	15	
Rest*	109.4 ± 20.81	94.53 ± 22.73	1.292
Exercise*	110.8 ± 21.58	100.23 ± 19.24	1.035

*Expressed as mean of percentage of predicted ± one standard deviation.

In this study, eight men had radiographic changes compatible with simple CWP and between one and five years of underground mining experience. Six of these eight had done or were doing roof bolting, and two of these had fired shot. The four who were nonsmokers had either airway obstruction or bronchitis or both, but this relationship did not hold among the four smokers. One of the smokers had done spot welding prior to employment in the mines.

Discussion

Among coal miners, cigarette smoking is a significant respiratory exposure, which may influence the development of impairment and disability due to coal dust exposure. In 1963-1965, Lainhart[10] found that 61 percent of the 2,516 coal miners he studied regularly smoked cigarettes and that 20 percent denied ever smoking. Of the 8,495 men surveyed in the IAS between 1969-1972, 54.4 percent were smokers. Of the miners in that study, 20.2 percent had never smoked. Theoretically, therefore, any test which is significantly affected by cigarette smoking would not be generally applicable as a survey test for respiratory abnormalities due to coal dust.

In the current study, diffusing capacity has been shown to be significantly lower in smoking miners than in nonsmoking miners. A large majority of nonsmoking miners tested had results which were within normal limits. These results agree with those reported by Ulmer and Reichel,[11] Podlesch et al,[12] Lyons et al,[13] and Lapp and Seaton,[14] in that no significant reduction in diffusing capacity was found in nonsmoking miners whether or not they had radiographic evidence of simple CWP.

Rasmussen and Nelson[2] studied symptomatic miners and ex-miners and, although they concluded

Table 8—*Diffusing Capacity in Six Underground Bituminous Coal Miners Who Had Stopped Smoking*

Subject, No.	Age, Yrs.	Underground, Yrs.	DL Rest**	DL Exer.**	X-ray, Category
1	40	2	102	101	1
2	50	22	104	*	1
3	41	21	100	85	0
4	41	23	125	70	0
5	46	21	83	99	0
6	28	4.5	103	85	0

*Not exercised owing to history of angina.
**Expressed as percentage of predicted.

that cigarette smoking was not associated with reduced diffusion and increased A-a gradients, their data showed a higher D_L and a lower A-a gradient for nonsmokers than for those who smoked more than 15 cigarettes per day. If such impairment is due to coal mining and is as frequent as they report, the current study should have uncovered more nonsmoking active miners with decreased D_L.

Cigarette smoking for even a relatively short period has been shown to impair D_L in nonminers; however, cessation of smoking restores the D_L to the normal range.[3] Krumholz and his associates[4] found a significantly increased single breath D_L in six smokers after three weeks of abstinence. All six of the miners in this study who had stopped smoking between two and six months prior to testing had normal resting diffusing capacities. However, this group is too small to attribute any significance to this observation.

This study involved active coal miners who were not selected on the basis of respiratory symptoms or radiographic evidence of CWP. Men from large mines were used in an attempt to have similar dust exposure levels for both smokers and nonsmokers. Indeed, occasionally two or three men from the same face operation were evaluated on the same day. Only a few miners used protective respirators occasionally and none had used them regularly.

In summary, this study demonstrated a significant reduction in steady state D_L in coal miners who regularly smoked cigarettes but a normal D_L in nonsmoking miners. Because of the difficulty in interpreting the significance of an abnormal D_L in the cigarette smoking miner, it is doubtful that this testing procedure would be helpful in detecting occupationally related respiratory impairment in working coal miners.

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