AN ANALYSIS OF THE EFFECTS OF SMOKING AND OCCUPATIONAL EXPOSURE ON SPIROMETRY AND ARTERIAL BLOOD GASES IN BITUMINOUS COAL MINERS IN SOUTHERN WEST VIRGINIA

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INTRODUCTION

In evaluating the presence of pulmonary disability in coal miners, the Federal Black Lung Program utilizes primarily spirometry and arterial blood gas analysis for objective assessment of the degree of pulmonary insufficiency in a given individual. Emphasis is placed upon the measurement of the forced expiratory volume in one second (FEV_1) to assess the degree of bronchial obstruction and the arterial oxygen tension at rest and during exercise to assess the efficiency of alveolar gas exchange. Presently utilized disability standards for the FEV_1 and the arterial oxygen tension in the Federal Black Lung Program were established and promulgated in 1980.[1]

The effects of the inhalation of coal mine dust on lung function, particularly the oxygenating function, have been controversial. In fact, the need for arterial blood gas measurements in determining the presence of pulmonary disability in the coal mining population has been questioned in a recent study.[2] Because our experience with the results of pulmonary function tests and arterial blood gas studies performed both at rest and during exercise indicated the importance of arterial blood gas measurements in the disability evaluation of coal miners, a formal analysis of data we had collected over the past few years was undertaken. The results of that analysis constitute the basis of this report.

METHODS

Both spirometry and arterial blood gas studies were obtained on a cohort of 2725 active miners or ex-miners who were evaluated for disability. With few exceptions the men studied were or had been actively employed as miners in the bituminous coal mines in southern West Virginia. Data collected on each applicant included age, height, weight, smoking history and the number of years employed in mining. For the purpose of this analysis, only the years spent in underground mining were utilized. A minimum of three forced vital capacity tracings were obtained on each subject utilizing a Stead-Wells spirometer. The FEV_1 measurements were obtained from the forced vital capacity tracings. At least two of the FEV_1 values had to agree within 5% for the study to be acceptable. The largest FEV_1 was reported. For the arterial blood gas study an arterial catheter was inserted usually in the radial artery, occasionally in the brachial artery. Following insertion of the arterial line the subject was permitted to rest in the sitting position for 15 to 20 minutes before a sample of arterial blood was drawn and analyzed immediately for oxygen tension, carbon dioxide tension and pH. Each subject was then exercised on a treadmill for a period of 6 minutes to ensure the achievement of a steady state. The intensity of exercise was increased in incremental steps until the subject was either too fatigued to continue or an oxygen consumption of about 25cc/Kg/minute was achieved which is the oxygen consumption observed in men undergoing moderately heavy manual labor. Subjects were provided rest periods of approximately 30 minutes between incremental increases in exercise. Expired gas was collected to permit the calculation of oxygen consumption and arterial blood samples were obtained during the sixth minute of exercise and analyzed immediately. In the earliest studies the arterial blood samples were analyzed in one blood gas analyzer. In subsequent studies which represented the majority, each arterial sample was analyzed simultaneously in either two or three different blood gas analyzers. All of the blood gas analyzers were calibrated immediately before and after each sample was analyzed. Agreement within 3 mm Hg was required for arterial oxygen tension values and within 2 mm Hg for arterial carbon dioxide tension values for the measurements to be acceptable. The average values for the blood gas tensions so measured was reported. The disability standard for the FEV_1 was 60% of the age, sex and height corrected predicted normal value. For the arterial oxygen tension the disability standard was 60 mm Hg at normal carbon dioxide tension or the oxygen tension adjusted for decreasing carbon dioxide tension.

RESULTS

Table I indicates that 732 or about 27% of the cohort of 2725 met the presently utilized disability standards of the Federal Black Lung Program. Slightly less than 5% were disabled by the FEV_1 standard alone while almost 18% were disabled by the arterial blood gas standard. Mean age, mean number of pack years of cigarette smoking and mean number of years of underground mining were similar in the four groups analyzed.

All of the subjects disabled by arterial blood gas criteria alone had FEV_1 values above 60% of the predicted normal. Considering any FEV_1 value equal to or above 80% of predicted normal to be in the normal range, values in the 60–79% range then indicate mild bronchial obstruction. Table II indicates that two-thirds of those disabled by the arterial blood gas standard alone had FEV_1 values within the normal range, indicating the absence of physiologically significant bronchial obstruction.

Table III indicates that about 14% of the subjects who had never smoked met disability standards. The majority of those who met disability standards were disabled as the result of arterial blood gas abnormality. Almost 26% of ex-smokers met disability/standards, the majority on the basis of arterial blood gases alone. Approximately 34% of the subjects who were smokers at the time of the study met disability standards. As in the case of the never smokers and ex-smokers, the majority of smokers met disability standards as the result of arterial blood gas abnormality.

If we combine ex-smokers and smokers into a single group of those who were actively exposed to cigarette smoke, the percentage of those disabled is about 30%. This figure is approximately twice the percentage of disabled who had never smoked.

Table IV indicates a direct relationship between the percentage of those disabled by arterial blood gas alone and the number of years spent underground. On the other hand note

Table I

Frequency of Disability by Mean Age, Mean Years Underground, Mean Years of Smoking and Type of Pulmonary Insufficiency

	Disabled			Non-Disabled
	Spirometry Only	ABG Only	Both	
Number of Subjects	128 (4.7%)	486 (17.8%)	118 (4.3%)	1993 (73.1%)
Mean Age	53.4	54.4	55.1	52.2
Mean Years Underground	23.4	27.2	24.5	23.8
Mean Pack Years	21.4	23.5	25.2	19.3

Table II

FEV_1 in Those Disabled by ABG Criteria Only

Percentage of Observed FEV_1 to Predicted	Disabled	Non-Disbled
60-79%	160 (32.9%)	399 (20.0%)
≥ 80%	326 (67.1%)	1594 (80.0%)
Total	486	1993

Table III
Frequency of Disability by Smoking Status and Type of Pulmonary Insufficiency

	Disabled			Non-Disabled	Total
	Spirometry Only	ABG Only	Both		
Never Smokers	21	66	7	564	658
Ex-Smokers	·41	141	38	627	847
Smokers	66	279	73	802	1220
Total	128	486	118	1993	2725

Table IV
Frequency of Disability by Duration of Underground Mining and
Type of Pulmonary Insufficiency

	Disabled			Non-Disabled	Total
Years Under-ground	Spirometry Only	ABG Only	Both		
1-9	18 (7.3%)	28 (11.3%)	15 (6.1%)	186 (75.3%)	247
10-19	32 (4.6%)	89 (12.7%)	20 (2.8%)	557 (79.8%)	698
20-30	37 (4%)	168 (18%)	43 (5%)	665 (73%)	913
31+	41 (5%)	201 (23%)	40 (5%)	585 (67%)	867
Total	128 (4.7%)	486 (17.8%)	118 (4.3%)	1993 (73.1%)	2725

the relative constancy of the percentage of those disabled by spirometry alone despite the increasing number of years spent underground.

Using the height-weight ratio as an indicator of the presence of obesity, the data did not reveal an increase in prevalance of obese subjects meeting disability standards by arterial blood gas criteria. In fact the data suggest that those individuals with disabling arterial blood gas values tended to be leaner than those without disabling values. Also of interest is the fact that slightly more than one-fourth of the 604 subjects who met arterial blood gas disability standards did so at rest only. The remainder of the 604 subjects met arterial blood gas disability standards at rest and exercise or during exercise only. These two latter observations will be presented and discussed in a subsequent publication.

DISCUSSION

There is general agreement that the inhalation of coal mine dust in susceptible individuals produces a disease process which has its origins in the small airways[3] and produces the characteristic pathologic lesion known as the coal macule.[4] In a relatively small percentage of those afflicted the disease process goes on to progressive massive fibrosis which may distort the lung airways. Since the 80–90% of the total airway resistance in man resides in the large airways and since the FEV_1 is determined primarily by an increase in airflow resistance in the large airways, it is not surprising that a disease process affecting primarily the small airways will not usually produce a significant decrease in the FEV_1 in the majority of those affected. Thus the fact that about 3% of those subjects who never smoked were disabled by spirometry alone is not an unexpected finding. It is also interesting to note that only slightly in excess of 5% of those who smoked were disabled by spirometry alone. Published studies document separate effects of cigarette smoking and the inhalation of coal mine dust on decrements in FEV_1.[5,6,7]

On the other hand recent studies have demonstrated the fact that in coal miners abnormalities of alveolar gas exchange consisting of an increased alveolar-arterial gradient for oxygen as well as decreases in arterial oxygen tension occur both at rest as well as during exercise without significant decrement in the pulmonary diffusing capacity.[8] Using radioactive isotopes and sophisticated computer technology Susskind and his group have demonstrated the presence of regional uneven distribution of alveolar ventilation to pulmonary capillary blood flow in nonsmoking bituminous coal miners sufficient to explain an observed increase in alveolar-arterial oxygen gradient and decrease in oxygen tension. In that study 19 of the 20 coal miners studied had impaired gas exchange for oxygen while only 4 of the cohort had minimal airway obstruction.[9] Thus the explanation for impaired gas exchange appears to reside primarily in the presence of uneven alveolar ventilation-pulmonary capillary blood flow relationships which is the most common cause of arterial desaturation in diseases diffusely affecting the small airways.

It must be noted that our data were obtained on miners and ex-miners who were applying for disability and thus represent a cohort of subjects of poor pulmonary health. Our data are not representative of the universe of coal miners. Yet it is instructive to note the similarity of findings in Schiffman's analysis of anthracite miners in Pennsylvania who had applied for disability benefits.[10] Furthermore, studies in asymptomatic coal miners have demonstrated impairment in alveolar gas exchange for oxygen, both at rest and during exercise, though quantitatively less marked than those noted in our study.[8,11,12]

CONCLUSIONS

1. The inhalation of coal mine dust produces significant effects on lung function and arterial blood gases in the absence of cigarette smoking.
2. The major functional pulmonary problem produced by the inhalation of coal mine dust appears to be impairment of the oxygenating function of the lung. Published studies suggest that this problem is caused by an increase in regional inhomogeneity of the alveolar ventilation pulmonary capillary blood flow relationships with resultant increase in the size of the physiologic shunt which causes a decrease in arterial oxygen tension.
3. Of lesser frequency, but nonetheless present, was a significant increase in the airway resistance as measured by a decrease in the FEV_1 as the result of the inhalation of coal mine dust.
4. The use of arterial blood gas studies is a justified and important component of disability evaluation among many of those applying for benefits under the Federal Black Lung Program.

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