Closing Volume in Coal Miners[1-3]

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SUMMARY

Closing volume and closing capacity were determined in 82 working Appalachian coal miners and in a comparable group of control subjects. Abnormalities of closing volume and closing capacity were related to other measurements of pulmonary function. The relationship of smoking history, dust exposure, and presence of pneumoconiosis and bronchitis to elevations of closing volume and closing capacity was determined. It was shown that nonsmoking miners had elevated closing volume and closing capacity when compared to control subjects. Miners who were smokers or ex-smokers also had elevated closing capacity when compared to control subjects. Neither bronchitic symptoms nor the radiographic presence of pneumoconiosis were associated with an elevation of closing volume or closing capacity.

Introduction

Previous studies carried out in the Appalachian Laboratory for Occupational Respiratory Diseases have shown that as the category of simple coal workers' pneumoconiosis (CWP) increases, there is no appreciable effect on ventilatory capacity as measured by spirometry (1). However, we have been able to show that simple CWP leads to an increase in the residual volume, and that the size of the increment is related to the category of pneumoconiosis (2). Similarly, other studies carried out in our laboratory have shown that miners with categories 2 and 3 of simple CWP may show frequency dependence of dynamic compliance and a reduction of maximal expiratory flows despite normal spirometric values (3, 4).

The characteristic pathologic lesion of simple CWP is the coal macule. This consists of an accumulation of coal dust around the first and second order respiratory bronchioles, often accompanied by some reticulin fibrosis and some dilatation of the respiratory bronchioles, the latter often referred to as focal emphysema (5). Because these pathologic changes occur in the physiologically "silent" zone of the lungs, it is not surprising that spirometric tests may not differ significantly from predicted normal values, and that only by using special techniques is it possible to detect the physiologic effects produced by simple CWP.

It is now accepted that a significant increase in air flow resistance may occur in those airways < 2 mm in diameter without affecting significantly either total airway resistance or standard spirometric tests of ventilatory capacity (6). Such distal airway obstruction has been shown to be associated with an increase in the residual volume (6) and frequency dependence of dynamic compliance (7) and a reduction in maximal expiratory flows, particularly at lower lung volumes (4). Recently, measurement of the closing volume of the lung has been advocated as a simple test for the detection of obstruction with-

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2 Mention of brand names does not constitute endorsement by the U. S. Public Health Service.

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in peripheral airways (8). We therefore decided to measure closing volume in a group of miners to determine whether coal mining has an effect on this index of peripheral airway function and, if so, whether the change could be related to the radiographic presence of CWP or to other indices of dust exposure.

Materials and Methods

The subjects selected were 82 working coal miners from two nearby mines in northern West Virginia and southwestern Pennsylvania. All had been examined in the first round of the National Coal Study in 1970 (9). A control population of 58 men was chosen from among employees of the Appalachian Center for Occupational Safety and Health and West Virginia University Medical Center.

The following were performed on each miner as part of the examination in the National Coal Study: (*1*) posteroanterior and left lateral chest radiographs; (*2*) a complete occupational, smoking, and respiratory symptom history using the British Medical Research Council (MRC) questionnaire (10); (*3*) spirometry recorded as flow-volume curves of a maximal expiratory forced vital capacity maneuver (11). The chest radiographs were interpreted according to the UICC/Cincinnati Classification of the Pneumoconioses (12). The consensus reading assigned to each radiograph by the readers for the National Coal Study was used in this study (9).

The MRC questionnaire was administered to all the control subjects, and a posteroanterior chest radiograph was obtained if the subject had not had a film interpreted as normal within the preceding 12 months.

Each participant voluntarily agreed to undergo some simple tests of ventilatory capacity. These were recorded as maximal expiratory flow-volume curves using a system described previously (11). Forced vital capacity (FVC), forced expiratory volume in one sec (FEV_1), and forced expiratory flow at 50 per cent of the FVC (FEF_{50}) were measured from the maximal expiratory flow-volume curves. After 2 practice maneuvers, the next 3 curves were recorded and the largest was taken as the reported value for each subject. Total lung capacity and airway resistance were measured in a constant volume plethysmograph by the technique of DuBois and coworkers (13). A minimum of 3 technically acceptable maneuvers were recorded on each subject, and the mean values for the total lung capacity and for airway resistance at functional residual capacity were reported.

Closing volume was determined using Anthonisen's modification (14) of the Fowler single-breath nitrogen test (15), except that no breathholding was allowed between inspiration and expiration, and expiratory flow was controlled voluntarily by the subject to between 0.4 and 0.5 liter per sec by having him observe a meter display of the flow tracing. The subject exhaled maximally to residual volume, inhaled slowly to total lung capacity from a balloon in a box containing 100 per cent O_2, then without breathholding slowly exhaled at a flow between 0.4 and 0.5 liter per sec to residual volume again. Expired N_2 concentration was sampled via a needle valve just beyond the lips with a rapidly responding nitrogen analyzer (Model 350, Med Science, St. Louis, Mo.) and recorded on the Y axis of an X-Y recorder (Model 7034A, Hewlett-Packard Co.). Expired volume was recorded with an electronic waterless spirometer (Model 800, Ohio Medical Products, Madison Wisc.) and displayed on the X axis of the X-Y recorder.

Each subject generated at least 3 acceptable curves, which were defined as those in which the inspiratory and expiratory flows were kept within the limits set above and in which the difference between inspiratory and expiratory vital capacities were not greater than 5 per cent. In some subjects as many as 5 curves were necessary to obtain 3 acceptable tracings. All the curves were measured by one experienced technician without knowledge of whether the subject was a miner or control subject. The mean of the values calculated from 3 acceptable curves was the value reported for closing volume and added to the residual volume to obtain closing capacity.

Closing volume was measured as the volume from the onset of the abrupt change in slope of the N_2 concentration (the beginning of phase IV) to the end of the expiration. Closing capacity was calculated by adding to the closing volume the residual volume determined in the body plethysmograph.

Statistical comparisons between the miners and

TABLE 1

CHARACTERISTICS OF THE CONTROL AND MINER POPULATIONS

Characteristics	Control Subjects	Miners
No. of subjects	58	82
Age, years		
Mean	37.9	40.7
SD	11.7	12.8
Height, cm		
Mean	175.9	173.9
SD	6.9	6.4
Weight, kg		
Mean	78.5	81.1
SD	10.6	11.5
Current smokers, %	20.7	43.9
Ex-smokers, %	27.6	30.5
Nonsmokers, %	51.7	25.6
Bronchitics, %	6.9	42.7
Category of coal workers' pneumoconiosis, %		
0	100.0	70.7
1		18.3
2		7.3
3		3.7

TABLE 2

MEAN LUNG VOLUMES AND FLOWS (AGE, HEIGHT, AND WEIGHT ADJUSTED)

Index	Control Subjects			Miners		
	Smokers	Ex-Smokers	Nonsmokers	Smokers	Ex-Smokers	Nonsmokers
No. of subjects	12	16	30	36	25	21
Total lung capacity, liter	6.37	7.33	7.07	7.13	6.94	6.90
Residual volume, liter	1.54	2.14	1.84	2.04	1.99	1.90
Forced vital capacity (FVC), liter	4.83	5.19	5.25	5.10	4.96	5.00
Forced expiratory volume in 1 sec (FEV_1), liter	3.86	4.01	4.11	3.75	3.75	3.83
$FEV_1/FVC \times 100$, %	79.5*	77.1	78.1	73.6*	75.3	75.9
Forced expiratory flow at 50% of forced vital capacity, liter per sec	5.04	4.86	5.24	4.34	4.44	4.45

*Difference between means of smoking control subjects and smoking miners was significant ($P < 0.05$).

control subjects were made using a covariance technique (16), the covariates in the model being age and, in some instances, pack years of cigarette smoking. The 95 per cent confidence level was the critical cutoff point in testing.

Results

The characteristics of the miners and control subjects are shown in table 1. The miners averaged nearly 3 years older, 2 cm shorter, and 2 kg heavier than the control subjects and included more current smokers (43.9 per cent versus 20.7 per cent). The prevalence of bronchitis among the miners was also higher than among the control subjects (42.7 per cent versus 6.9 per cent), mainly owing to the larger number of current smokers but also probably related to prolonged dust inhalation (17). The distribution of categories of CWP in the miners in this study was similar to that found in the sample of working miners in the National Coal Study (9).

The age-, height-, and weight-adjusted mean values obtained by analysis of covariance for total lung capacity, residual volume, FVC, FEV_1, $FEV_1/FVC\%$, and FEF_{50} for miners and control subjects by smoking status are listed in table 2. The only significant difference between the mean values, when comparing miners and control subjects within a smoking category, was found in the $FEV_1/FVC\%$. The smoking miners had an adjusted mean $FEV_1/FVC\%$ that was lower than that of the smoking control subjects. In none of the other comparisons between miners and control subjects within the same smoking category were the differences significant.

Age-adjusted mean values for closing volume as a percentage of vital capacity (CV/VC%) for control subjects and miners by smoking category are shown in figure 1. The only significant difference between control subjects and miners was in the nonsmoker category.

Age-adjusted mean values for closing capacity as a percentage of total lung capacity (CC/TLC%) for control subjects and miners by smoking category are shown in figure 2. These comparisons showed that in each smoking category the miners had a significantly larger mean value for CC/TLC% than did the control subjects.

In figure 3 are plotted the age-adjusted mean values for CV/VC% and CC/TLC% for the miners according to whether they had radiographic evidence of pneumoconiosis. For this comparison, all miners with radiographs classified as category 1/0 or higher were considered to have pneumoconiosis. It can be seen that there was no significant difference in either CV/VC% or CC/TLC% between the miners with and without pneumoconiosis.

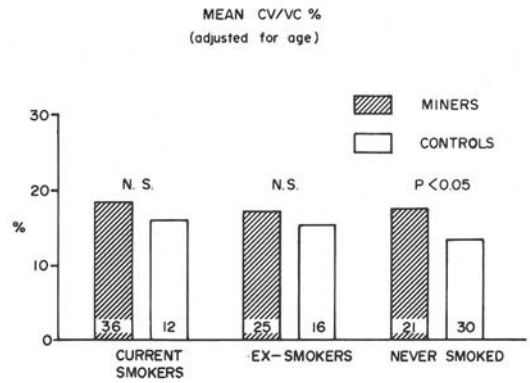

Fig. 1. Mean closing volume as a percentage of vital capacity for miners and control subjects by smoking status.

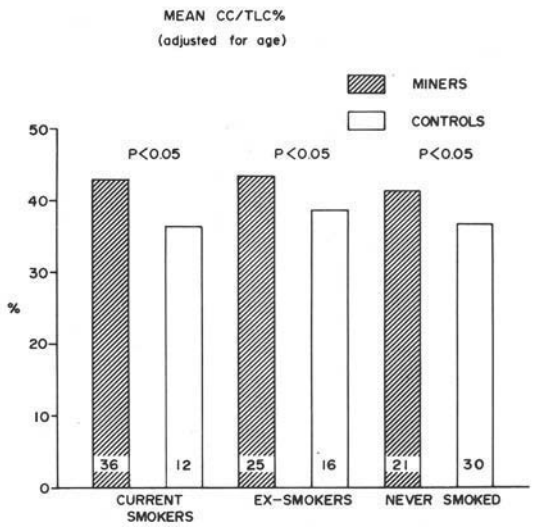

Fig. 2. Mean closing capacity as a percentage of total lung capacity for miners and control subjects by smoking status.

Discussion

In the sample of miners selected for this study, age-adjusted mean values for CV/VC% among nonsmokers and age-adjusted mean vaues for CC/TLC% in all smoking categories were significantly elevated when compared to control subjects. Insofar as an elevated closing capacity and closing volume have been assumed to be a reflection of abnormal function in the peripheral airways, it might be inferred that such impairment is present in a proportion of coal miners.

The mechanisms leading to increased CV/VC% and CC/TLC% are not fully understood. In their original report, Milic-Emili and associates (18) suggested that the airways in the dependent zones of the lungs closed owing to the distribution of a pleural pressure gradient from apex to base of the lung caused by gravity. In subsequent studies, abnormalities of closing volume and closing capacity have been assumed to be the results of disordered function within peripheral airways because the subjects being studied also demonstrated frequency dependence of dynamic compliance (19) and/or reduced flow rates at the lower lung volumes (6). Recently, Hoeppner and co-workers (20) showed that cigarette smokers without cough and phlegm have elevated CV/VC% and CC/TLC% when compared to age-matched nonsmokers, but these investigators were unable to find other confirmatory evidence of obstruction in peripheral airways. Indeed, their data strongly suggest that the elevation of CC/VC% and CC/TLC% resulted from shifts in the pressure-volume curves and a concomitant loss of lung recoil.

In previous reports we have shown that miners with simple CWP often have elevated residual volume (2) and frequency dependent dynamic compliance (3) and reduced maximal expiratory flows, particularly at the lower lung volumes (4), in conjunction with normal spirometric values for FEV_1 and FVC. Such findings have, for the most part, been attributed to abnormalities in the function of peripheral airways; similar findings have been observed in bronchitic subjects (21), asthmatics in remission (22), cigarette smokers (23), and children with cystic fibrosis (24).

In a previous study (4) we demonstrated that an appreciable proportion of nonsmoking miners with frequency dependence of dynamic compliance in the presence of normal lung recoil had a slightly increased upstream resistance, implying obstruction in the peripheral airways. However, a minority of nonsmoking miners showed an even greater reduction in maximal expiratory flow at low lung volumes in the absence of both frequency dependence of dynamic compliance and an elevated upstream resistance. In the latter subjects, the reduced maximal expiratory flows appeared to be a consequence of loss of lung recoil. Unfortunately, measurements of CV/VC% and CC/TLC% were not made in these subjects at the time of the original study.

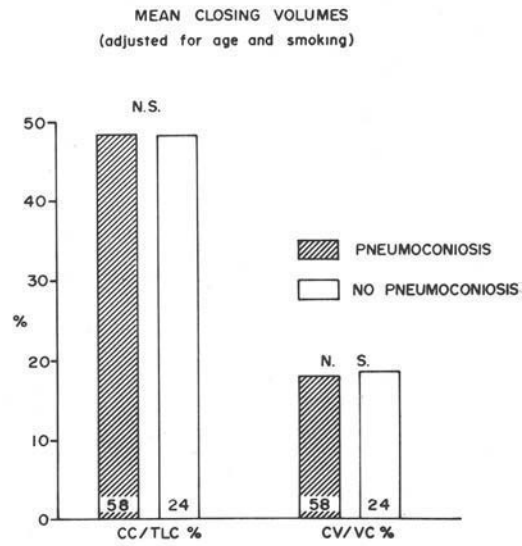

Fig. 3. Mean closing capacity and closing volume for miners with and without pneumoconiosis.

The site and pathologic features of the coal macule and its associated focal emphysema suggest that it might lead to loss of lung recoil, to intrinsic obstruction within the peripheral airways, or to both, and that either or both of these mechanisms could account for the elevated closing volume and closing capacity demonstrated in this study.

It is interesting that the only significant difference between the age-adjusted mean values for the routine tests of lung volumes and flow rates was in the FEV_1/FVC ratio. The FEV_1/FVC ratio of the smoking miners was lower than that of the smoking control subjects. This index of lung function has generally been believed to reflect predominantly obstruction in the large (> 2 mm diameter) airways. This difference between the smoking control subjects and the smoking miners might be a reflection of effects of mining on the large as well as the peripheral airways of the miners over and above those due to smoking.

It could be argued that the elevations in CV/VC% and CC/TLC% in the miners reflected a greater prevalence of bronchitis among them (42.7 per cent for miners versus 6.9 per cent for control subjects). Age-adjusted mean values for CC/TLC% and CV/VC% in control subjects and miners according to the presence of bronchitic symptoms are shown in figure 4. It is apparent that the differences between control subjects and miners were not the result of differences in prevalence of bronchitic symptoms, because the differences in closing volumes were significant only among the subjects without bronchitis. Martin and associates (25) also showed that bronchitic symptoms did not correlate with functional abnormality in cigarette smokers. The possibility exists that the miners may have answered the questions regarding respiratory symptoms differently than the control subjects, or that the questionnaire may be insufficiently sensitive to detect "early bronchitis" and in this regard may lag behind measurement of CV/VC% and CC/TLC%. An alternative explanation may be that the presence of bronchitis obscures whatever it is about mining that elevates closing volumes. Finally, it is possible that had there been a larger number of bronchitics in the control population, the differences between them and the miners might have shown the same changes as in the nonbronchitics.

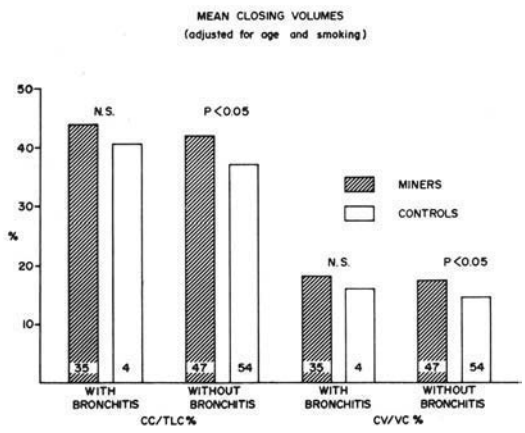

Fig. 4. Mean closing capacity and closing volume for miners and control subjects by presence or absence of bronchitis.

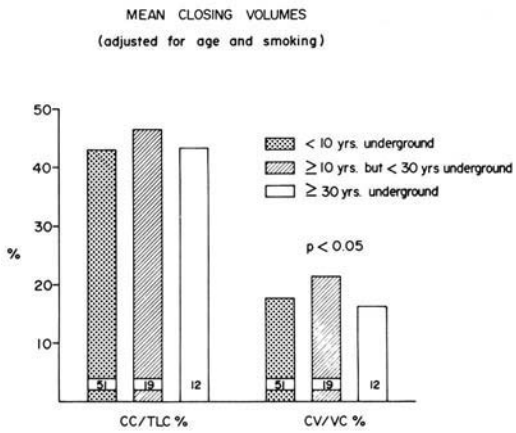

Fig. 5. Mean closing capacity and closing volume for miners by underground exposure.

The most obvious explanation for the differences in CC/TLC% in all smoking categories and CV/VC% between nonsmoking control subjects and nonsmoking miners is the fact that the miners have inhaled coal mine dust, whereas the control subjects have not. Because the radiographic presence of pneumoconiosis is an indicator of dust retention, we looked for an association between pneumoconiosis and elevation of CC/TLC% and CV/VC%. Because the number of miners with categories 2 and 3 of CWP was small, subjects with all categories of simple CWP were compared to those without CWP. As shown in figure 3, no significant differences existed; hence, the elevated values for CC/TLC% and CV/VC% cannot be accounted for by the presence of simple CWP.

Although the category of simple CWP is related to the coal dust content of the lungs postmortem (26), and also to respirable dust exposure in life (27), there are those who feel that

the number of years spent working underground provides a better indication of the total respiratory insult to which the subject has been exposed. Furthermore, it has been suggested that physiologic abnormalities are more likely to be related to total dust exposure or some other similar index, such as years spent underground, than to exposure to the respirable fraction (28). Age-adjusted mean values for CC/TLC% and CV/VC% for the miners plotted versus years of underground exposure are shown in figure 5. The age-adjusted mean value for CV/VC% of the intermediate exposure group was significantly higher than that for either the low or high exposure groups. The apparent anomaly of a lower age-adjusted mean value for CV/VC% among the miners who had worked longer than 30 years underground might be explained on the basis that these men constituted a select survivor sample of unusually healthy persons; however, this is surmise. Most other studies have shown the CC/TLC% to be more sensitive than the CV/VC% in demonstrating abnormalities of peripheral airways function in subjects who are cigarette smokers, asthmatics, or otherwise felt to have "early" obstructive airways disease. We are at a loss to explain why in this study the CV/VC% was more sensitive than the CC/TLC% in relation to years of underground exposure.

In summary, it is apparent that nonsmoking miners showed significant elevations of the closing volume and that miners regardless of smoking status showed significant elevations of closing capacity when compared to an age-matched control population. We could find no single explanation for these abnormalities; although in some instances they were probably the consequence of an increased upstream resistance due to bronchiolitis, in others they were more probably the result of decreased lung recoil. No relationship was apparent between the presence of bronchitis as determined by responses to the MRC questionnaire and elevation of closing volume and closing capacity, a fact that may imply that the presence of cough and sputum is not as sensitive an indicator of early bronchitis or bronchiolitis as is measurement of closing volume and closing capacity or that bronchitis might obscure whatever it is that causes closing capacity to become elevated in miners. Finally, it should be stressed that at present there is no justification for assuming that the presence of an abnormal closing volume or closing capacity in a coal miner in any way presages the onset of irreversible obstructive airway disease.

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