Effect of Simple Anthracite Pneumoconiosis on Lung Mechanics*

David M. F. Murphy, M.B.; Louis F. Metzger, B.A.; Dennis A. Silage, Ph.D.; and Charles M. Fogarty, M.D.

A respiratory questionnaire was administered to 20 miners with simple anthracite coal workers' pneumoconiosis (CWP) and ten normal subjects. Lung function studies which included lung mechanics and small airways disease measurements were also performed. Seventeen of the miners admitted to having symptoms of bronchitis. No significant differences were demonstrated between the two groups for vital capacity (VC), forced vital capacity (FVC), forced expiratory volume in one second (FEV₁), and three seconds (FEV₃), midmaximal flow rate (FEF₂₅-⁷⁵%), and peak flow rate (PEFR). A significant decrease in the maximum expiratory flow rate at 50 percent of vital capacity (V₅₀max%) was detected; however, this was not evident when the flow rate was corrected for lung volume. Also, there were no significant differences in lung volumes, diffusing capacity (Dco) and diffusing coefficient (Dco/TLC). The mean static expired compliance (Cstₐ) was significantly increased in the anthracite miners, but no difference in specific compliance (Cstₐ/FRC) could be demonstrated. Also, no significant differences were detected in the mean values of any of the tests of small airways disease. There is little evidence of significant alterations in lung mechanics or small airway narrowing in miners with simple anthracite pneumoconiosis.

The majority of coal mined in the United States is of the bituminous variety; small quantities of anthracite coal are still mined in Eastern Pennsylvania, but in Europe, anthracite coal continues to be an important energy source. Coal mine dust from anthracite mines in Pennsylvania may have higher concentrations of silica than that found in bituminous coal mines in other parts of the United States, as miners from this region develop coal workers' pneumoconiosis (CWP) which at autopsy has been shown to be associated mainly with the presence of coal macules but also with smaller numbers of silicotic nodules. As the silicotic nodule and the coal macule are both found in relation to the respiratory bronchiole, they could potentially compress or constrict the lumen of the bronchiole. Studies in coal workers with simple bituminous CWP have demonstrated physiologic evidence of small airway narrowing and slight changes in lung mechanics. A group of miners with simple anthracite CWP was investigated in order to determine whether there was physiologic evidence of small airway narrowing and/or significant abnormalities in lung mechanics.

METHODS

Twenty miners with simple pneumoconiosis from the anthracite coal region of Pennsylvania were selected for study. Miners with significant heart or lung disease were excluded. Prior lung function tests were available and only nonobstructed miners (FEV₁/FVC>70%) were included. Chest roentgenograms were read using the ILO/UC classification. Miners with predominantly category 2 simple pneumoconiosis were included. Six miners had category 1; 12 had category 2; and two had category 3 simple pneumoconiosis. There were ten with the p type opacity; seven with the q type opacity; and three with the r type opacity. There were 14 nonsmokers and six exsmokers, none of whom had smoked in the ten years prior to the study. Their ages ranged from 59 to 77, with the mean of 68.5 years. Ten lifelong nonsmokers comprised the control group. Their mean age was 68.0 years with a range of 59 to 82 years. A modified Medical Research Council (MRC) questionnaire was used to obtain a complete occupational, smoking, and respiratory symptom history on all subjects. Chronic bronchitis was defined as cough and sputum on most days for three months for two consecutive years. An ECG was also evaluated prior to inclusion of the subject in the study.

Lung Function Measurements

Spirometry was performed using a waterless high fidelity spirometer (model 800, Ohio Medical Products, Madison, WI) attached to a microcomputer with graphic display. Following two practice trials, flow volume curves from three FVC maneuvers were recorded. Superimposition of the three flow volume loops at total lung capacity allowed drawing of a maximal flow volume envelope. Following three
vital capacity breaths of a mixture of 80 percent helium and 20 percent oxygen, the forced vital expiratory maneuver was repeated and recorded. From three such tracings, whose FVCs were within 5 percent of the maximum FVC on air, a maximal flow volume envelope was similarly derived. Alignment of both maximal envelopes at residual volume allowed calculation of the VisoV and change in flow rate at 50 percent of VC. Flow and volume were corrected to body temperature pressure saturated (BTPS).

The following measurements were recorded from the flow volume curves on air: FVC, FEV1, FEV3, Vmax50%, and FEF25-75%. Lung volumes were measured by the closed circuit helium technique.8 Diffusing capacity was measured by the single breath method of Ogilvie and co-workers.a A ∆Vmax50% was expressed as a percentage of the FVC (VisoV).

Esophageal pressure was measured using a pressure transducer (Stratham PM 131 TC) attached by a polyethylene tube of 3 mm diameter and 120 cm length to a 10 cm latex balloon which was positioned in the lower one third of the esophagus with the tip positioned 10 cm above the diaphragm.10

Transpulmonary pressure was obtained by electronically subtracting mouth pressure from esophageal pressure. Pressure and volume tracings were recorded. Three reproducible deflational and inflational pressure volume curves were accepted following constant volume history. Lung compliance was measured from the linear portion of the pressure volume curve above functional residual capacity (FRC). The Pst-TLC was also obtained from this curve.

By visually displaying the subject's tidal volume on the XY screen of a recorder (Electronics for Medicine), it was possible for the subject to maintain a constant tidal volume (500 ml) and to ensure there was no change in end-expiratory volume at various breathing frequencies. Volume was measured using a waterless spirometer (Ohio 840, Ohio Medical Products). The frequency response of the esophageal balloon-pressure transducer-tubing system was flat within ±5 percent up to a 6 Hz. Dynamic compliance was obtained by plotting points representing instantaneous pressure and volume at points of zero flow on the XY coordinates of a cathode ray oscilloscope (Electronics for Medicine Recorder DR8). Ten respiratory cycles were recorded at each breathing frequency. The slope of a line joining the points indicated the change in transpulmonary pressure and volume, at points of zero flow. Dynamic compliance was recorded at respiratory frequencies of 15, 30, and 60 breaths per minute. A constant volume history preceded each measurement and was expressed as a percentage of static inspired compliance (Cdyn/Cstat,%). Frequency dependent compliance was defined as a progressive fall in Cdyn/Cstat,% to less than 65 percent at 60 breaths per minute.11

Closing volume was measured using Anthonisen's modification12 of Fowler's single breath oxygen test.13 The subject exhaled to residual volume, then inhaled 100 percent oxygen to TLC and without breath holding expired to residual volume (RV). Expiratory flow was maintained below 0.5 L/s using a fixed size orifice in the expiratory line. Each subject generated three reproducible curves, where the difference between expiratory and inspiratory vital capacity was not greater than 5 percent. The predicted normal values were those of Buist and Ross.14 From the flow volume curves and the pressure volume curves, maximum flow static recoil pressure curves (MFSR) were constructed. The results were compared to the curves from the normal subjects and the normal values reported by Ostrow and Cherniack.15

Table 1—Characteristics of Subjects

<table>
<thead>
<tr>
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<th>Miners</th>
<th>Controls</th>
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<tbody>
<tr>
<td>No. of Subjects</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>66 ± 0.98</td>
<td>68 ± 2.62</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>170.7 (1.8)</td>
<td>167 (2.94)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>75.67 ± 2.48</td>
<td>75.00 ± (3.15)</td>
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Statistical Analysis

Statistical analysis was carried out using the Mann Whitney U test for comparison of the mean values. The significance in the two trial test was set at the 5 percent level (p < 0.05).16

RESULTS

There were no significant differences in the anthropometric data between the two groups (Table 1). Seventeen of the miners admitted to symptoms of chronic bronchitis compared to none of the control subjects. Mean values for ventilatory capacity, closing volume and diffusing capacity are shown in Tables 2 and 3. No statistically significant differences were found for TLC, RV, functional residual capacity (FRF), FVC, FEV1, or FEV3. There were no differences in the ratios of FEV1/FVC% and FEV3/FVC% between the groups, but the Vmax50% was decreased in the miners. When corrected for volume, this difference was no longer demonstrable. There was no significant differences in the mean values for diffusing capacity (Dco) or Dco/TLC (Table 2).

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Table 2—Lung Function Results

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<thead>
<tr>
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<th>Miners</th>
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<tr>
<td>TLC (L)</td>
<td>6.19 ± 0.27</td>
<td>6.21 ± 0.28</td>
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<tr>
<td>RV (L)</td>
<td>2.18 ± 0.17</td>
<td>2.06 ± 0.15</td>
</tr>
<tr>
<td>VC (L)</td>
<td>4.04 ± 0.19</td>
<td>4.15 ± 0.21</td>
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<tr>
<td>FEV1 (L)</td>
<td>2.83 ± 0.12</td>
<td>3.16 ± 0.19</td>
</tr>
<tr>
<td>FEV3 (L)</td>
<td>3.49 ± 0.15</td>
<td>3.67 ± 0.20</td>
</tr>
<tr>
<td>FEV1/FVC x 100</td>
<td>74.8 ± 1.74</td>
<td>80.5 ± 2.43</td>
</tr>
<tr>
<td>FEV3/FVC x 100</td>
<td>91.0 ± 1.14</td>
<td>91.9 ± 1.15</td>
</tr>
<tr>
<td>Vmax50 (L/s)</td>
<td>3.20 ± 0.27</td>
<td>4.46 ± 0.43*</td>
</tr>
<tr>
<td>FEF25-75% (L/s)</td>
<td>0.54 ± 0.05</td>
<td>0.69 ± 0.07</td>
</tr>
<tr>
<td>PEFR (L/s)</td>
<td>8.46 ± 0.38</td>
<td>10.13 ± 0.54</td>
</tr>
<tr>
<td>Dco (ml/min/mmHg)</td>
<td>24.9 ± 2.58</td>
<td>20.9 ± 1.20</td>
</tr>
<tr>
<td>Dco/TLC (ml/min/mmHg/L)</td>
<td>3.45 ± 0.20</td>
<td>3.99 ± 0.35</td>
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*Statistically significant p < 0.05.
Table 3—Lung Mechanics

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<tr>
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<tr>
<td>Pst TLC (cm H₂O)</td>
<td>18.65 ± 1.52</td>
<td>26.12 ± 4.15</td>
</tr>
<tr>
<td>Pst/TLC (cm H₂O/L)</td>
<td>3.13 ± 0.29</td>
<td>4.06 ± 4.06</td>
</tr>
<tr>
<td>Cstat₄ (L/cm H₂O)</td>
<td>0.36 ± 0.02</td>
<td>0.26 ± 0.03*</td>
</tr>
<tr>
<td>Cstat/FRC</td>
<td>0.12 ± 0.01</td>
<td>0.12 ± 0.03</td>
</tr>
<tr>
<td>VisoV (%)</td>
<td>34.97 ± 3.67</td>
<td>30.04 ± 3.51</td>
</tr>
<tr>
<td>A Vmax50 (%)</td>
<td>31.72 ± 4.22</td>
<td>41.0 ± 8.84</td>
</tr>
<tr>
<td>CC/TLC (%)</td>
<td>52.31 ± 1.76</td>
<td>49.1 ± 1.92</td>
</tr>
<tr>
<td>CV/VC (%)</td>
<td>29.88 ± 1.69</td>
<td>25.9 ± 1.99</td>
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<tr>
<td>ΔNₑ/L (%/L)</td>
<td>1.90 ± 0.26</td>
<td>1.55 ± 0.15</td>
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*Statistically significant p < 0.05.

measurements was examined, there were minor changes in the pressure volume curves between the two groups. The Cstat, was increased in the miners, but when corrected for lung volume (Cstat₄/FRC), this difference vanished (Table 3). There were no differences in Pst°TLC. Two miners showed frequency dependent compliance (Fig 1), one of whom had an increased upstream resistance, and the other an increased CC/TLC%, abnormal Vmax 50%, and abnormal VisoV.

Only three miners had abnormal MFSR curves indicating increased upstream resistance (Fig 2). Of the two miners who showed an increased upstream resistance but no evidence of frequency dependent compliance, both had an increased CC/TLC%. One also had an abnormal Vmax50% and VisoV%.

No significant differences between the two groups were noted in the following indices of small airway narrowing: Cdyn/Cstat, VisoV/VC%, CC/TLC%, CV/VC%, and ΔNₑ/L (Table 3).

**DISCUSSION**

Hart and Aslett\(^\text{17}\) first proposed in 1942 that a relationship existed between the rank of coal mined and the incidence of pneumoconiosis. In 1963, Lieben and McBride\(^\text{18}\) reported marked regional differences in both claims for compensation and the number of deaths attributed to occupational lung disease, with significantly higher rates occurring in the anthracite coal region. Subsequent studies have confirmed the existence of higher prevalence rates for both simple and complicated CWP in United States anthracite miners.\(^\text{19}\) In the past, the differences have been attributed to either the silica content of the coal mine dust or the rank of the coal mined.\(^\text{20}\)

Recent studies from the United Kingdom have suggested that the higher prevalence of pneumoconiosis in anthracite mines may be due to the fact...
that high rank collieries may have higher mass concentrations of respirable dust. Morgan and co-workers reported that the ventilatory capacity of anthracite miners, both with and without pneumoconiosis, was slightly lower than that of bituminous miners. In addition, they noted significantly higher residual volumes in the anthracite miners with pneumoconiosis, and they suggested that this resulted from either small airway obstruction or focal emphysema.

Several occupational or environmental disorders of the lung parenchyma have in common physiologic abnormalities which suggest small airway narrowing. Among these are asbestosis, hypersensitivity pneumonitis, and simple bituminous CWP. The common morphologic findings associated with these conditions is a lesion involving the respiratory bronchiole. For example, the peribronchiolar fibrosis of asbestosis, the coal macule of simple CWP, and the bronchiolo-alveolitis of hypersensitivity pneumonitis are all localized to the respiratory bronchiole, although the latter may also involve the terminal bronchiole.

Simple CWP in miners from the anthracite region of Pennsylvania is characterized by the histologic findings of both the presence of coal macules, which are typical of simple CWP, and silicotice nodules which are typical of silicosis. This combination of morphologic lesions gave rise to the older descriptive item “anthrasilicosis.” The coal macule is a peribronchiolar collection of coal dust which has been carried to the region of the respiratory bronchiole by alveolar macrophages. Fine reticulin fibers are often found among the coal dust, and under certain conditions, the smooth muscle of the bronchiolar wall atrophies, and the respiratory bronchiole dilates, giving rise to the condition of “focal emphysema.” Thus, the coal macule is strategically placed to cause either narrowing or dilation of the respiratory bronchiole. Studies from the United Kingdom have shown that the packing of coal dust particles in early dust deposits varies considerably and corresponds with the degree of tissue reaction to the dust. Where the tissue reaction was slight, the coal dust particles were densely packed; on the other hand, a vigorous cellular reaction was associated with much wider spacing which in turn was associated with a low coal content of the dust but high noncoal (particularly silica) content.

The silicotic nodule which is the morphologic lesion characteristic of simple silicosis, consists of a whorled, concentric collection of fibrotic tissue found in close proximity to the respiratory bronchiole. The mature human silicotic nodule is identified by three zones: A central region of hyaline connective tissue having a whorled appearance, surrounded by a zone of concentrically dispersed fibers, and finally, an outer zone of peripheral collagen with a more reticular arrangement. Gross and Brieger have shown in rats that following an intratracheal injection of a fine crystalline silica dust, there develops a multifocal inflammation which involves the respiratory bronchioles and the adjoining alveolar ducts and eventually leads to obliteration of the respiratory bronchioles. Heppleston has suggested that the dust lesion of CWP may be distinguished from that seen in silicosis by the following three criteria: (1) stenosis of respiratory bronchioles is not a feature; (2) inflammatory changes in bronchiolar walls are inconsistent; and (3) disruption of bronchiolar and alveolar walls is not a primary event, although it may be seen in advanced lesions. In anthracite coal mines with CWP, both coal macules and silicotic nodules can be identified in the lung. Frank simple silicosis only develops in miners when the percentage of silica in the inhaled dust approaches 18 percent. The importance of silica as a cause of pneumoconiosis in coal miners in the United Kingdom has recently been emphasized.

As the morphologic lesions which occur in anthracite miners with CWP may affect the respiratory bronchiole, anthracite miners with simple CWP were examined to determine if there was physiologic evidence of small airway narrowing, but despite using several sophisticated techniques, these abnormalities could not be detected in a significant
number of miners. Only two miners showed frequency-dependent compliance, one of whom had an increased upstream resistance and the other an increased CC/TLC% and abnormal ΔVmax50% and VisoV/VC%. This incidence of an abnormal dynamic compliance is similar to that reported in a study of bituminous miners with simple CWP. However, it should also be noted that miners with simple CWP in the United States are often over the age of 60 years, and Begin and co-workers have reported frequency dependent behavior of dynamic compliance in normal subjects in this age group.

Although increases in CV/VC% have been previously described in bituminous miners with simple CWP, we were unable to demonstrate statistically significant differences in CC/TLC%, CV/VC%, or ΔN2/L between the anthracite miners and control subjects (Table 3).

The only significant difference noted between the two groups was a decrease in Vmax50% which disappeared when the flow rates were corrected for lung volume (Table 2). Hall and co-workers have reported a marked decline in Vmax50% over a four-year period without significant changes in FEV in a group of bituminous miners with simple CWP, and decreases in Vmax50% have been noted in other studies of miners with simple CWP. In this study, evidence of small airway narrowing in the majority of the anthracite coal workers was not detected. This would be in keeping with the coal macule being the predominant morphologic lesion, and the fact that this is not usually associated with bronchiolar stenosis. When the lung mechanics measurements were analyzed, Cstat, was significantly higher in the miners. However, when corrected for lung volume this difference could no longer be demonstrated (Table 3). The maximum static recoil pressure in the anthracite miners almost achieved significance (Table 3), but again after correction for lung volume this difference between the groups was removed. These findings are similar to that reported in bituminous miners with CWP and suggest a close similarity between anthracite and bituminous miners with simple CWP. In contrast, studies of lung mechanics in subjects with frank simple silicosis have revealed a tendency for compliance to decrease.

Elastic recoil pressure is one of the major factors determining maximum expiratory rate. If emphysema was common in anthracite miners with CWP, it would not be surprising to find a decrease in expiratory flow rates. The absence of such a decrease, a normal coefficient of retraction, and a normal specific compliance make significant emphysema unlikely. Increased upstream resistance does not occur in uncomplicated emphysema but rather indicates small airway narrowing. The majority of coal workers in this study had normal MFSR curves; only three of the 20 miners had increased upstream resistance. In the two miners where increased upstream resistance was not associated with frequency dependent compliance, both showed an increased CC/TLC% and one of these also had a decreased ΔVmax50% and an increased VisoV.

A recent study by Lyons and co-workers reported no differences in the extent and type of emphysema in a group of smoking and nonsmoking miners with pneumoconiosis, with substantial degrees of emphysema occurring in the nonsmoking miners with simple CWP. This study included only miners claiming disability and is therefore not truly representative of pneumoconiotic miners. If emphysema is indeed present in anthracite miners with simple CWP, its physiologic impact is slight, as it neither affects gas transfer, (as there was no difference in diffusing capacity between the two groups [Table 2]), nor gives rise to significant differences in lung mechanics when changes in lung volume have been accounted for.

Previous studies have reported decreases in single breath diffusing capacity in simple bituminous CWP with the p type opacity. In this study, no decrease in diffusing capacity was demonstrated in this subgroup of miners. Englert and Decoster measured diffusing capacity in a group of 43 miners with anthrasilicosis and reported reductions in only three miners. There was no difference in the mean diffusing capacity between the miners and controls in this study, and no individual miner had a reduced diffusing capacity.

The majority of miners (85 percent) in this study, all of whom were current nonsmokers, had chronic bronchitis. This is rather higher than the 46.5 percent reported by Kibelstis and co-workers in bituminous miners over 60 years of age. This did not appear to cause any decrement in lung function, and in particular, there was no evidence of an effect on the large airways. Morgan has recently pointed out that the decrease in ventilatory capacity which occurs as a result of industrial bronchitis is related to lifetime dust exposure and that the predominant physiologic effect is on the large rather than the small airways. Hankinson and co-workers had previously reported that dust-induced bronchitis in coal miners was associated with decreases in peak flow and Vmax50% but that flow rates at lower lung volumes were unchanged. In the present study, neither a decrease in peak flow rate nor Vmax50%
could be demonstrated between the groups after correction for lung volume. However, the small number of subjects in this study may limit detection of this abnormality.

In conclusion, the present study demonstrates little alteration in lung mechanics or evidence of small airway narrowing in a group of nonsmoking anthracite miners with simple CWP, despite the presence of chronic bronchitis in the majority of those miners.

REFERENCES

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35 Teculescu DB, Stanescu DC, Picak L. Pulmonary mechanics in silicosis. Arch Environ Health 1967; 14:461-68
Sixth Annual Infectious Diseases Symposium

The Sixth Annual Infectious Diseases in Clinical Practice: An International Symposium, will be held February 5-12 in Davos, Switzerland. The symposium is sponsored by the University of California, San Francisco. For information, contact Extended Programs in Medical Education, UCSF School of Medicine, Room 569-U, San Francisco 94143 (415: 666-4251).

Clinical Approach to Exercise Testing

This course will be held at the Hyatt Orlando Hotel, Orlando, Florida, February 3-5. The course is sponsored by the University of South Florida College of Medicine. For information, contact Dr. Stephen P. Glasser, University of South Florida College of Medicine, 12901 North 30th Street, Tampa 33612 (813: 974-2880).

Ultrasound for Clinicians

This eighth annual postgraduate course offered by the Department of Radiology, Brigham and Women's Hospital, and the Department of Continuing Education, Harvard Medical School, will be held February 28-March 2 in Boston. For information, contact the Department of Continuing Education, Harvard Medical School, 25 Shattuck Street, Boston 02115 (617: 732-1525).