Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: http://www.tandfonline.com/loi/uaoh20

Miners with Clinically Important Declines in FEV_1: Analysis of Data from the U.S. National Coal Study

M. L. Wang , E. L. Petsonk , M. D. Attfield , S. R. Short , L. F. Beeckman , B. Bonnett & J. L. Hankinson

To cite this article: M. L. Wang , E. L. Petsonk , M. D. Attfield , S. R. Short , L. F. Beeckman , B. Bonnett & J. L. Hankinson (1996) Miners with Clinically Important Declines in FEV_1: Analysis of Data from the U.S. National Coal Study, Applied Occupational and Environmental Hygiene, 11:7, 989-995, DOI: 10.1080/1047322X.1996.10390001

To link to this article: http://dx.doi.org/10.1080/1047322X.1996.10390001

Published online: 24 Feb 2011.

Submit your article to this journal

Article views: 7

View related articles

Citing articles: 5 View citing articles

Full Terms & Conditions of access and use can be found at
http://www.tandfonline.com/action/journalInformation?journalCode=uaoh20

Download by: [Stephen B. Thacker CDC Library] **Date:** 04 April 2017, At: 07:04

Miners with Clinically Important Declines in FEV_1: Analysis of Data from the U.S. National Coal Study

M.L. Wang,[A,B] *E.L. Petsonk,*[A,B] *M.D. Attfield,*[A]
S.R. Short,[A,B] *L.F. Beeckman,*[A] *B. Bonnett,*[A] *and J.L. Hankinson*[A]

[A]National Institute for Occupational Safety and Health, 1095 Willowdale Road, Division of Respiratory Disease Studies, Morgantown, West Virginia 26505-2888; [B]Section of Pulmonary and Critical Care Medicine, P.O. Box 9166, WVU School of Medicine, Morgantown, West Virginia 26506-9166

Several previous studies, including the U.S. National Study of Coal Workers' Pneumoconiosis (NSCWP), have demonstrated a loss of FEV_1 over time that is related to occupational dust exposure in miners. However, much of the variation in loss of FEV_1 in the mining cohorts studied remains unexplained. This study sought to identify individual miners with clinically important FEV_1 declines and investigate risk factors for the declines. Subjects were chosen from NSCWP longitudinal cohorts. All miners with at least 6 years follow up (N = 5900) were grouped into strata based on age, height, smoking status, gender, and initial FEV_1. Within these strata, pairs of miners were selected whose annual rate of FEV_1 decline differed by more than 60 ml/y, and 344 pairs were entered into the analysis. Miners with high rates of decline were assigned to the study group; those with low rates of decline served as referents. On the initial questionnaire, study miners had more cough and phlegm than referents ($p < 0.01$). At follow-up, prevalences of reported cough, phlegm, dyspnea, wheezing, bronchitis, asthma, and emphysema were all significantly higher in the study group than in the referent group; whereas prevalence of radiographic coal worker's pneumoconiosis (CWP) was not different. The distribution of case and referent miners by geographic mining region was different ($p = 0.052$). Weight gain in the study group was significantly greater than in the referent group. Study and referent groups were similar for age at entering mining and coal mining tenure. However, when mining region effects were reduced by only including pairs whose case and referent were from same region (N = 94 pairs), cases had significantly more mining tenure than referents. A group of coal miners with clinically important longitudinal lung function declines was identified. Mining tenure was a predictor of serious functional decline, when the effect of mining region was taken into account. Additional studies are underway in this group to define other potential risk factors, disease processes, and mechanisms for these changes. WANG, M.L.; PETSONK, E.L.; ATTFIELD, M.D.; SHORT, S.R.; BEECKMAN, L.F.; BONNETT, B.; HANKINSON, J.L.: MINERS WITH CLINICALLY IMPORTANT DECLINES IN FEV_1: ANALYSIS OF DATA FROM THE U.S. NATIONAL COAL STUDY. APPL. OCCUP. ENVIRON. HYG. 11(7):989-995; 1996.

Background

The relationship between underground coal mining exposure and lung function loss is well established.[1-5] For example, Marine and colleagues analyzed cross-sectional data from British coal miners and found that both dust exposure and smoking are associated with clinically important respiratory dysfunction, and their separate contributions to obstructive airway disease in coal miners appear to be additive.[3] Data from a cross-sectional study of U.S. miners showed that the decrease in lung function was associated with dust exposure after adjustment for age in both smoking and nonsmoking miners.[5] Similar findings were found in longitudinal studies.[6,7] However, much of the observed variation in ventilatory function declines in coal miners remains unexplained. In this connection, Soutar and Hurley reported on a group of miners, some of whom showed marked functional losses in relation to coal mine dust exposure, and observed, "In general, the effect of dust on lung function was not affected by smoking habit, and the reason for the excessive effect of dust in some men must be sought elsewhere. A third factor (or more), whether intrinsic susceptibility to the effects of dust or an environmental factor not so far identified, must be sought to explain why these men suffered such severe lung damage in response to their exposure to respirable dust."[4]

The goal of this study was to identify individual miners from the U.S. National Study of Coal Workers' Pneumoconiosis (NSCWP) longitudinal cohorts who had experienced clinically important FEV_1 declines, and to compare differences in respiratory illnesses and symptoms, and potential risk factors, between workers with rapid lung function loss and those with stable spirometric findings over the years of follow-up.

Subjects and Methods

Subjects

The investigation is based on participants in the NSCWP, which comprises a total of four rounds of spirometry and questionnaire surveys.[8] The first round (R1), which took place between 1969 and 1971, involved 31 underground mines distributed across the United States, in all major coal fields. Participation was better than 90 percent at all mines, and 9078 miners were examined. The second round (R2) began in August 1972 and was completed in February 1975. Of the 31 mines studied in R1, 26 were restudied in R2. Nine new

mines were added, giving a total of 35 mines studied, and 9347 miners examined. The third round (R3) was performed between 1977 to 1981. Surveys were undertaken at 32 mines (including 23 of 31 from R1 and all 9 from R2) and 5275 miners participated. Round 4 (R4) was a community based survey, conducted from 1985 through 1988, consisting of a follow-up of over 3000 selected miners from R1 and R2.

Male miners common to R1 and R3, R1 and R4, or R2 and R4, (i.e., with at least six years follow-up (N = 5900)) were grouped by cohort into cells according to age, height, initial FEV_1, and smoking status. Age category was determined according to 5-year intervals (8 groups). Height category was determined according to 4-cm intervals (5 groups). Initial FEV_1, based on the maximum effort, was categorized using 500-ml intervals (8 groups). Mean annual FEV_1 declines were then calculated as the difference between the largest FEV_1 at the initial and final surveys, divided by the time between surveys. Miners whose smoking status remained the same at both rounds were categorized as current, former, or nonsmokers (3 groups). Miners whose smoking status changed from the initial to the final survey were excluded from the analysis.

For each cell containing at least two individuals, the miner with the greatest mean annual decline in FEV_1 was paired with the miner with the least mean annual decline. If the difference in mean decline of this pair was greater than or equal to 60 ml/y, the pair was selected for further study. After a pair of miners was selected, they were removed from the cell and the selection procedure repeated, until no more pairs could be selected. This selection process resulted in 141 pairs from R1 to R3, 68 pairs from R1 to R4, and 165 pairs from R2 to R4. Several miners who had attended three or four rounds were selected more than once. The selection process thus resulted in a total of 374 pairs of observations, but only 685 distinct individuals, since 49 miners were selected twice and 7 miners, three times.

Methods

The consistency of each subject's status was examined: if a miner had been selected more than once, and in one selection served as a case, while in the other as a referent, the miner was not included in the study; seven pairs were excluded for this reason. Second, the quality of spirometry performance was reviewed. Flow-volume curves for approximately 70 percent of all tests were available. These were screened by at least two investigators for acceptability of effort, satisfactory start of test, and the presence of cough or premature termination. Miners were excluded if either their initial or final test did not include at least one acceptable curve. This resulted in the elimination of 23 other pairs of observations from the study. Removal of these 30 pairs based on quality issues left 344 pairs of observations eligible for analysis, including 634 individual miners (46 miners being selected twice and 4 three times).

The Statistical Analysis System (SAS®) was used for data analysis.[9] Descriptive statistical analysis of data from cases and referents was performed using both group and matched pair comparison approaches.[10] The following items were analyzed: (1) Demographic parameters—age, sex, race, height, weight, and total years of school; (2) spirometry indexes—FEV_1, FVC, and FEV_1/FVC%; (3) coal mine exposure—total years of mining, total years of underground mining, total years of underground face work, mine regional distribution, age started mining, and interim respirable dust exposure; (4) smoking status—smoking category, age started smoking, cigarettes per day, and pack-years; (5) chest symptoms—cough, phlegm, dyspnea, wheeze, and stuffy nose; (6) chest illnesses—defined as a "yes" response to the question "Have you ever had . . . bronchitis, pneumonia, pleurisy, tuberculosis, asthma, or emphysema?"; and (7) radiographic category of pneumoconiosis, derived in a similar fashion to previous investigations in this cohort.[8]

Two sources of estimates of respirable dust exposure were available, assignable to miners seen at Round 3,[7] and Round 4.[11]

Separate preliminary analyses of the data from Rounds 1 to 3, Rounds 1 to 4, and Rounds 2 to 4 revealed that the results from the three separate data sets were very similar (data not shown). In the analysis presented below, results from the four rounds of examinations were combined into two data sets, with data from Round 1 and 2 combined as the initial observation, and data from Round 3 and 4 as the final observation. Cross-sectional and longitudinal comparisons of various variables between cases and referents were then conducted using the two combined data sets. For both group and matched pair comparisons of frequencies, chi square and paired chi square testing were used, and for continuous variables, *t* tests and paired *t* tests were performed. Differences for which $p \leq 0.05$ were considered significant.

Results

Results of Matching

On average, despite the matching, referents were 0.4 year younger and 0.25 inch shorter than the cases, while initial FEV_1 and FVC were 24 ml and 119 ml lower, respectively. These differences were small and of little practical importance. As planned, the distribution of smoking categories was identical in cases and referents; with a total 197 pairs of current smokers, 78 pairs of former smokers, and 69 pairs of nonsmokers.

Lung function change in cases by smoking status showed large annual FEV_1 declines for current smokers, former smokers and nonsmokers, of 99, 93, and 83 ml/y, respectively. FEV_1 declines in cases by age group were 102, 90, and 81 ml/y, for miners who were greater than 50 years, 40 to 50 years, and less than 40 years at the first survey, respectively. Average declines for the referents varied little across the age groups (Figure 1).

Demographic Variables

Matched pair *t* tests showed that, comparing cases to referents, the mean differences in initial weight and years of schooling were not significantly different. At follow-up, cases had gained on average 9.5 lb more weight than referents (Table 1).

Cross-sectional analyses of initial and final FEV_1, FVC, and FEV_1/FVC% showed that increasing age and smoking were associated with lower lung function in both cases and referents; this was most clearly seen at the final observation for FEV_1 and FVC (Figure 2A and B).

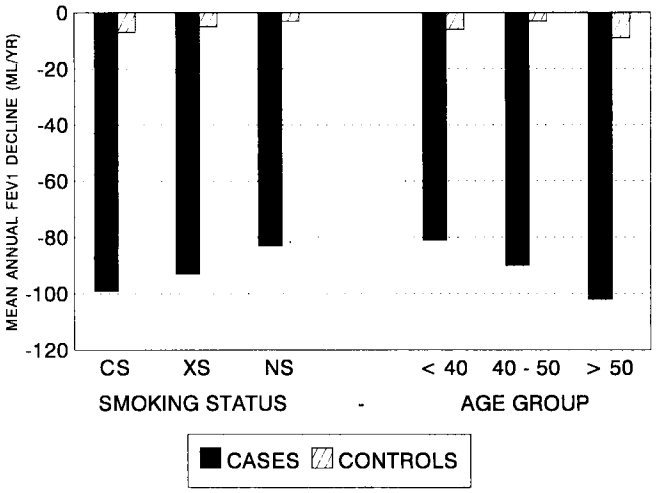


FIGURE 1. Annual FEV_1 decline in cases and referents by smoking status and age group, showing the marked functional declines observed over approximately 11 years of follow-up in the case miners compared to referents.

Coal Mining Work and Smoking Habits

For both cases and referents, total years of mining, years of underground mining, and years of face work averaged 13, 10, and 5 years, respectively, at the initial examination, and were 23, 18, and 7 years, respectively, at the final examination (Figure 3). However, the distribution of cases and referents by geographic mining region was different, with cases more likely to be found in western and southern U.S. coal fields ($P = 0.052$ by Mantel-Haenszel Chi-Square test, Figure 4). The tenure analysis was repeated using only the 94 pairs in which cases and referents worked in the same region. In this smaller group, matched pair *t* tests revealed that the miners with excess declines did have significantly greater mean job tenures. Initially in this group, cases had 1.8 more years of underground

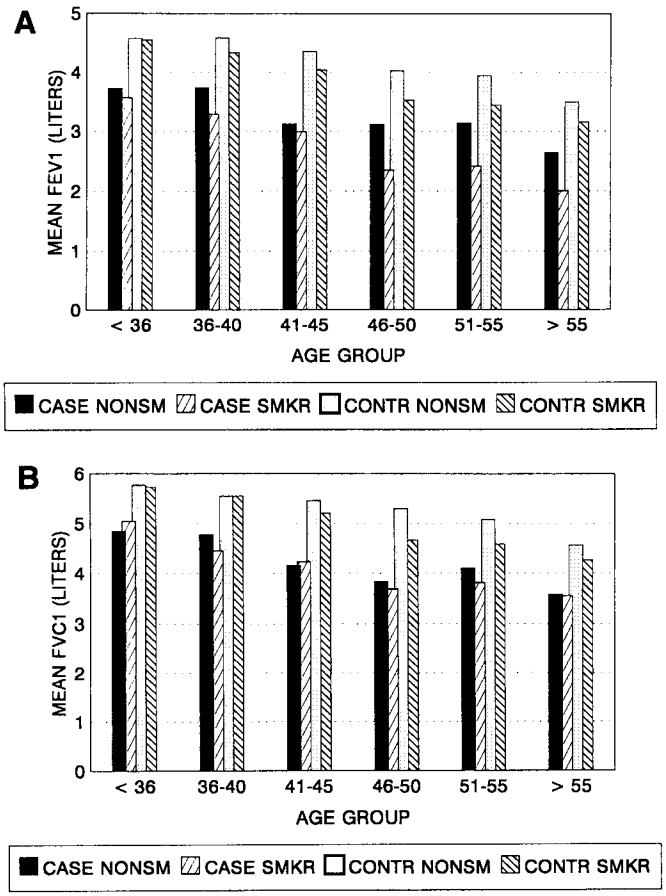


FIGURE 2. Mean FEV_1 (A) and FVC (B) at the final examination (Round 3 or Round 4) in cases and referents, by smoking status and age group, demonstrating the large and consistent functional deficits in cases, across age and smoking categories.

TABLE 1. Demographic Parameters and Spirometry Indices (344 Observation Pairs)

		Initial Survey		Final Survey	
		Cases	**Referents**	**Cases**	**Referents**
Age (y)	Mean	37.2	36.8	48.9	48.5
	SD	9.6	9.6	8.8	8.9
School (y)	Mean	10.4	10.5	10.4	10.6
	SD	2.3	2.1	2.4	2.2
Height (inches)	Mean	69.3	69.1	69.3	69.2
	SD	2.6	2.4	2.6	2.5
Weight (lb)	Mean	177.8	177.5	191.5	183.0[B]
	SD	32.2	29.8	39.3	26.0
FEV_1 (L)	Mean	3.91	3.89	2.82	3.83[B]
	SD	0.69	0.67	0.78	0.69
FVC (L)	Mean	5.25	5.13[A]	4.05	4.97[B]
	SD	0.77	0.82	0.89	0.82
FEV_1/FVC(%)	Mean	74.6	76.0[A]	69.6	77.2[B]
	SD	8.33	7.18	12.26	6.08

[A] $p < 0.05$.
[B] $p < 0.001$ for comparisons at the same survey between cases versus referents.
SD = Standard deviations.

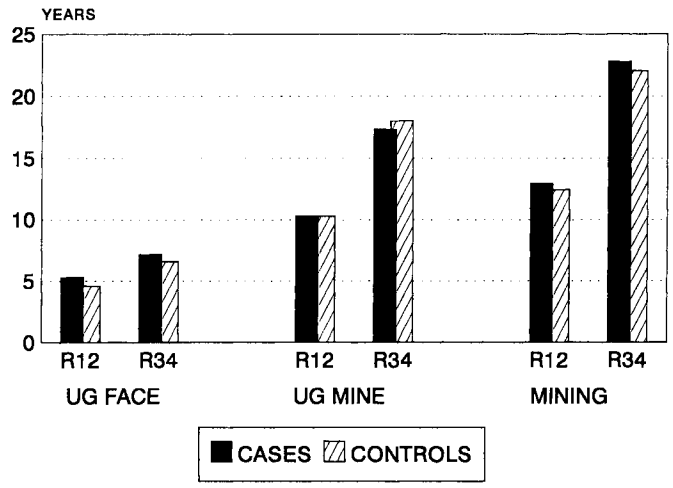
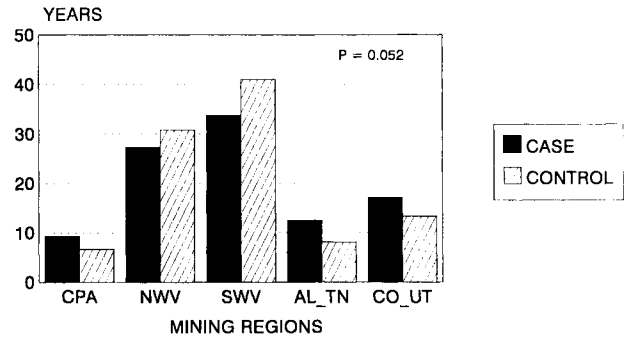


FIGURE 3. Mean total tenure in mining, tenure in underground mining, and tenure in underground face work for cases and referents at initial (Round 1 or Round 2) and final (Round 3 or Round 4) surveys. All three measures of tenure were similar in cases and referents.

face work than referents (P = 0.07). By the final survey, cases had 2.7 more years of face work (P = 0.02), and 2.4 more total years mining (P = 0.01), than referents. Study miners had significantly (P = 0.001) greater intersurvey dust exposure, using the R1 to R3 cases and referents (98 pairs). A similar, though smaller and nonsignificant, effect was found in the R1 to R4 group (62 pairs), but not in the R2 to R4 group (147 pairs).

For the smokers, the age at beginning smoking and, for former smokers, the age at quitting smoking, did not differ between cases and referents on either the initial or final questionnaires. The mean differences in cigarettes smoked per day between case and referent miners were 2.1 at the initial survey, and 1.2 at the final survey. On the initial, but not the final survey, both group and matched pair *t* tests indicated significantly greater mean cigarettes smoked per day and pack-years for case versus referent smokers (Table 2).



CPA - Central PA, NWV - Northern WV, OH, and Western PA
SWV - Southern WV, AL_TN - Alabama, Tennessee
CO_UT - Colorado, Utah

FIGURE 4. Proportion of case and referent miners from five U.S. mining regions, indicating that the miners who experienced severe functional declines demonstrated a different distribution by mining region when compared to the referent miners.

Chest Symptoms and Illnesses

Cases had a higher prevalence than referents of symptoms of cough and phlegm on the initial survey. By the final survey, affected miners had a significantly higher prevalence of cough, phlegm, bronchitis, dyspnea, wheezing, and reported asthma and emphysema. Radiographic Coal Worker's Pneumoconiosis (CWP), stuffy nose, and reported pneumonia and pleurisy did not differ between cases and referents at both the initial and final surveys (Figures 5 and 6). Longitudinal analyses of changes in symptoms and illnesses illustrated that, compared to referents, more cases reported development of cough, phlegm, dyspnea, wheeze, bronchitis, asthma, and emphysema. Odds ratios and chi-square results calculated using matched pair statistics for the initial and final data sets are shown in Table 3.

Discussion and Conclusions

The role of occupational exposures in the development of chronic obstructive lung diseases in exposed workers has been emphasized in several recent publications.[12–14] Oxman *et al.*, in an extensive review of the available literature, concluded

TABLE 2. Tobacco Smoking (344 Observation Pairs)

		Initial Survey		Final Survey	
		Cases	**Referents**	**Cases**	**Referents**
Age started smoking[A]	Mean	16.8	17.2	18.0	18.3
	SD	3.22	2.99	3.69	4.55
Age quit smoking[B]	Mean	33.3	33.0	35.0	33.1
	SD	8.62	7.85	9.35	9.23
Cigarettes per day	Mean	20.2	18.1[C]	19.6	18.4
	SD	8.40	8.87	8.91	8.88
Pack-years	Mean	18.3	16.0[D]	24.6	22.6
	SD	13.0	12.7	14.6	15.8

[A]Age started smoking, for current and former smokers.
[B]Age quit smoking, for former smokers.
[C]$p < 0.01$ for comparisons at the same survey between cases versus referents.
[D]$p < 0.05$.
SD = Standard deviations.

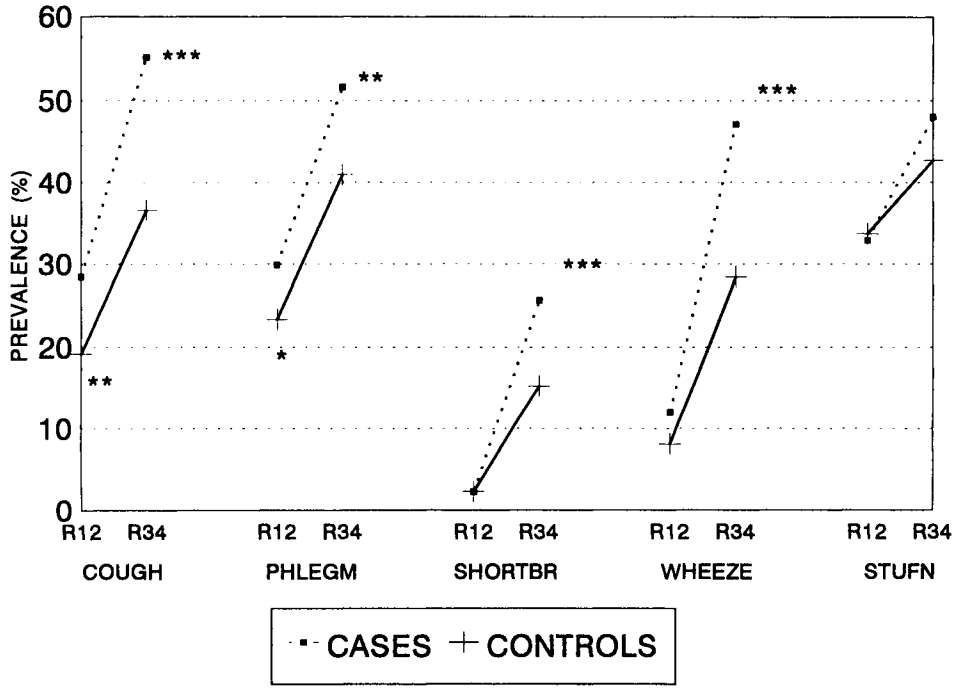


FIGURE 5. Chest symptoms in cases and referents at initial (Round 1 or Round 2) and final (Round 3 or Round 4) surveys. Even at the initial survey, case miners reported more cough and phlegm than matched referents.

that occupational dust exposure is an important cause of chronic obstructive lung disease.[15] In this study, we sought and identified a group of miners that had experienced large and clinically important declines in lung function over the approximately 11-year period of follow-up, in comparison to miners who were similar for age, height, smoking status, and baseline FEV_1. Information from the prior health surveys was analyzed for 344 matched pairs to investigate potential indicators of risk.

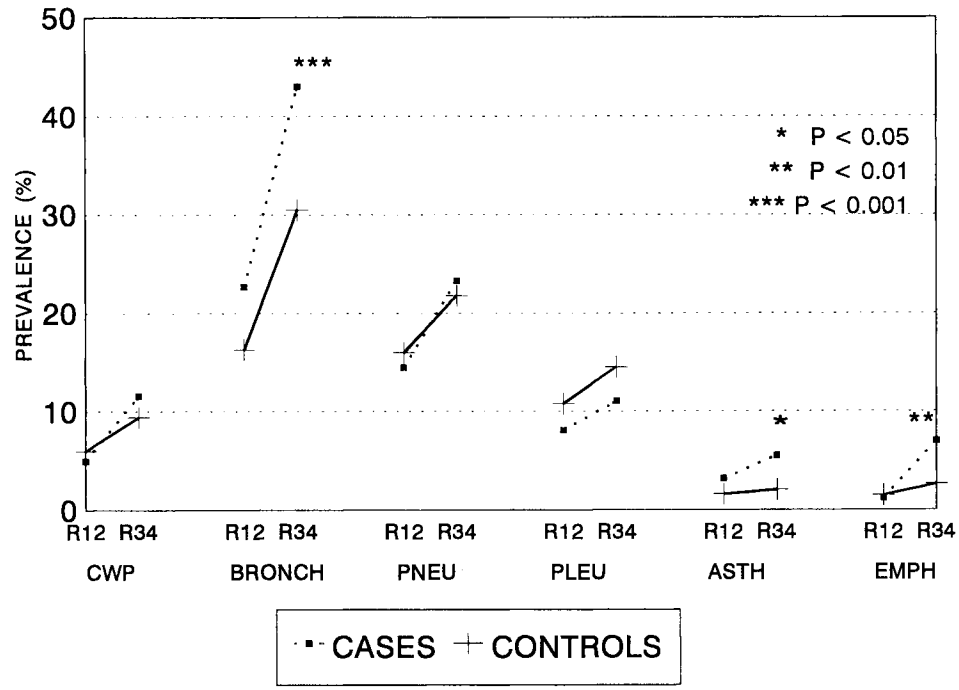


FIGURE 6. Chest illnesses in cases and referents at initial (Round 1 or Round 2) and final (Round 3 or Round 4) surveys. By the final survey, case miners reported more bronchitis and emphysema than referents, while radiographic changes of pneumoconiosis did not differ.

TABLE 3. Matched-Pair Comparisons of Symptoms and Illnesses (344 Observation Pairs, Number of Discordant Pairs)

	Case = Yes[A]	Referent = Yes[B]	Odds Ratio	Chi Square
Initial symptoms				
Cough	74	42	1.76	8.2[E]
Phlegm	72	49	1.46	4.0[C]
Bronchitis	59	37	1.59	4.5[C]
Dyspnea	8	8	1.00	0.0
Wheeze	35	22	1.59	2.5
Stuffy Nose	71	74	0.95	0.0
Final symptoms				
Cough	119	55	2.16	22.8[D]
Phlegm	105	68	1.54	7.4[E]
Bronchitis	106	63	1.68	10.4[E]
Dyspnea	69	33	2.09	12.0[D]
Wheeze	106	42	2.52	26.8[D]
Stuffy nose	92	74	1.24	1.7
Initial illnesses and chest radiographs				
Pneumonia	41	46	0.89	0.1
Pleurisy	21	30	0.70	1.3
Asthma	11	6	1.83	0.9
Emphysema	4	5	0.80	0.0
Radiographic CWP	12	15	0.80	0.1
Final illnesses and chest radiographs				
Pneumonia	59	54	1.09	0.1
Pleurisy	29	41	0.70	1.7
Asthma	19	7	2.71	4.6[C]
Emphysema	23	8	2.87	6.3[C]
Radiographic CWP	32	23	1.39	1.1

[A]Number of pairs in which the case answered "yes" and the referent "no" to the question.
[B]Number of pairs in which the case answered "no" and the referent "yes" to the question.
[C]$P < 0.05$.
[D]$P < 0.001$.
[E]$P < 0.01$.

Miners with excess declines tended to show a different geographic distribution than miners without these declines. Since miners were included only if they had participated in two surveys at least 6 years apart, the analysis approach tended to limit the range of mining tenures in the groups. Overall, no difference in tenure was noted between cases and referents. It was somewhat surprising that, when only the 94 pairs matched for geographic region were analyzed, affected miners had significantly greater exposure, as estimated by job tenure, than the unaffected group. Differences by mining region in the effect of dust on FEV_1 declines have been reported previously.[6,7]

In addition to tenure, dust exposures experienced between the initial and final medical surveys were found to explain some of the difference between the cases and referents. This was most evident for the R1 to R3 group, but was smaller or absent for the other two study groups. There are several reasons for this inconsistency. First, the exposure data for the R1 to R3 period were based on extensive personal sampling, often involving 30 samples or more per year for miners in some high exposure occupations. However, after R3, the frequency of sampling dropped considerably and changed to an area-based strategy for many occupations. Hence, it is possible that the increased variability inherent in the estimation of the post-R3 dust data led to weaker exposure estimates for the miners in the R1 to R4 and R2 to R4 groups, making the detection of a dust exposure effect less likely. Another reason may lie in the employment patterns of miners after R3. While the R1 to R3 group were all current miners at both medical survey endpoints, about half of those examined at R4 were no longer working in coal mining. If miners who were healthy tended to be retained at the mines or rehired, they would then accumulate further dust exposure. This additional exposure might lead to the referent miners appearing to have greater exposure than the cases, and result in a failure to find a clear dust exposure effect in the two groups involving R4 as compared to the R1 to R3 group.

At the final survey, miners who experienced excess lung function declines reported significantly higher prevalence of cough, phlegm, bronchitis, dyspnea, wheezing, and emphysema. The high proportion of cases who developed symptoms tends to validate the clinical importance of the FEV_1 declines. Interestingly, on the initial survey, a higher prevalence of symptoms of cough and phlegm was observed in the workers who subsequently developed clinically important declines in FEV_1, in spite of matching for height and initial FEV_1. This finding raises the question of the functional implication of phlegm production in dust-exposed workers. There is some evidence that chronic phlegm production may be a marker of susceptibility to dust effects on the lung. Rogan *et al.* noted that symptoms of productive cough were associated with reduc-

tions in FEV_1 greater than that expected from dust exposure.[1] In a group of 199 miners with bronchitic symptoms who left coal mining, the effect of cumulative dust exposure on FEV_1 appeared to be about three times the effect in unselected miners.[16] Further study of the lung biologic, pathologic, and cellular changes in dust-exposed workers with bronchitis might suggest potential mechanisms for these observations.

The fact that the miners with severe declines had more indications of chest symptoms on their initial examination indicates that this group was already less healthy at the start of their follow-up. This suggests a parallel with the "horse racing effect" described by Fletcher and Peto, whereby affected individuals show greater future declines in health than people initially not so affected. However, the analogy is not exact, for the case and referent miners in our study were chosen deliberately to have similar initial FEV_1 levels, as well as similar age and height. Hence, a horse-racing effect should not have been manifested in the case miners. Nevertheless, it may be that chest symptoms are precursors of more severe disease, in which case the excess seen initially in the case miners would imply a future faster decline in lung function.

Additionally, the miners with excess FEV_1 declines had gained significantly more weight than those with stable lung function. Whether these differences indicate a true association with environmental or biological factors requires further investigations.

The prevalence of radiographic pneumoconiosis at both initial and final surveys was not different in cases and referents, and did not account for the differences in FEV_1 declines observed. Previous investigations have suggested that radiographic simple CWP, in the absence of a high profusion, irregular opacities, or complicated disease, is not consistently associated with lung functional abnormalities.[17,18] Interpretation of the radiographic findings in this study is complicated by the use of existing data. Factors such as large inter-reader discrepancies in interpretations, missing data, and a change in the International Labour Office classification scheme that occurred between rounds may have affected the analysis. A rereading of the X-ray films from the different rounds, using identical readers and standards, might offer additional information on the relationship between radiographic evidence of pneumoconiosis and clinically important lung function changes in these miners. However, it is unlikely that the marked lung function losses observed in the case miners can be explained by the development of pneumoconiosis.

Other environmental factors, such as outdoor and indoor air pollution, have also been been implicated as affecting lung function level in population-based studies.[19,20] Socioeconomic status, childhood respiratory diseases, atopy, and nonspecific airway responsiveness are other factors that may potentially influence the level of lung function as well as changes observed over time.[21] The relative role of these factors in contributing to the clinically important impairments of lung function observed in these workers is unknown.

In conclusion, over 300 U.S. coal miners were identified who experienced clinically important declines in FEV_1, in comparison to miners matched for initial attributes and smoking status. Factors found to be associated with severe lung function loss included coal mine exposures, mining region, and initial symptoms of cough and phlegm. Further characterization of the mining environment, as well as socioeconomic, constitutional, and nonoccupational environmental factors in these matched pairs of miners may help to explain the disproportionate lung function losses observed in some dust exposed workers.

References

1. Rogan, J.M.; Attfield, M.D.; Jacobsen, M.; et al.: Role of Dust in the Working Environment in Development of Chronic Bronchitis in British Coal Miners. Br. J. Ind. Med. 30:217–226 (1973).
2. Morgan, W.K.C.; Handelsman, L.; Kibelstis, J., et al.: Ventilatory Capacity and Lung Volumes of US Coal Miners. Arch. Environ. Health 282:182–189 (1974).
3. Marine, W.M.; Gurr, D.; Jacobsen, M.: Clinically Important Respiratory Effects of Dust Exposure and Smoking in British Coal Miners. Am. Rev. Respir. Dis. 137:106–112 (1988).
4. Soutar, C.A.; Hurley, J.F.: Relation Between Dust Exposure and Lung Function in Miners and Ex-Miners. Br. J. Ind. Med. 43:307–320 (1986).
5. Attfield, M.D.; Hodous, T.K.: Pulmonary Function of U.S. Coal Miners Related to Dust Exposure Estimates. Am. Rev. Respir. Dis. 14:605–609 (1992).
6. Love, R.G.; Miller, B.G.: Longitudinal Study of Lung Function in Coal Miners. Thorax 37:193–197 (1982).
7. Attfield, M.D.: Longitudinal Decline in FEV_1 in United States Coalminers. Thorax 40:132–137 (1985).
8. Attfield, M.D.; Castellan, R.M.: Epidemiological Data on US Coal Miners' Pneumoconiosis, 1960 to 1988. Am. J. Public Health 82:964–970 (1992).
9. SAS Institute Inc.: SAS Procedures Guide, Version 6, Third Edition. SAS Institute Inc., Cary, NC (1990).
10. Kahn, H.A.; Sempos, C.T.: Statistical Methods in Epidemiology. Oxford University Press, New York–Oxford: (1989).
11. Seixas, N.S.; Robins, T.G.; Rice, C.H.; Moulton, L.H.: Assessment of Potential Biases in the Application of MSHA Respirable Coal Mine Dust Data to an Epidemiologic Study. Am. Ind. Hyg. Assoc. J. 51 (10):534–540 (1990).
12. Becklake, M.R.: Occupational Exposures: Evidence for a Causal Association with Chronic Obstructive Pulmonary Disease. Am. Rev. Respir. Dis. 140:S85–S91 (1989).
13. Korn, R.J.; Dockery, D.W.; Speizer, F.E.; et al.: Occupational Exposures and Chronic Respiratory Symptoms—A Population-Based Study. Am. Rev. Respir. Dis. 136:298–304 (1987).
14. Becklake, M.R.: Chronic Airflow Limitation: Its Relationship to Work in Dusty Occupations. Chest 88:608–617 (1985).
15. Oxman, A.D.; Muir, D.C.F.; Shannon, H.S.; et al.: Occupational Dust Exposure and Chronic Obstructive Pulmonary Disease. Am. Rev. Respir. Dis. 148:38–48 (1993).
16. Hurley, J.F.; Soutar, C.A.: Can Exposure to Coal Mine Dust Cause a Severe Impairment of Lung Function? Br. J. Ind. Med. 43:150–157 (1986).
17. Cockcroft, A.; Berry, G.; Cotes, J.E.; Lyons, J.P.: Shape of Small Opacities and Lung Function in Coalworkers. Thorax 37:765–769 (1982).
18. Lyons, J.P.; Campbell, H.: Relation Between Progressive Massive Fibrosis, Emphysema, and Pulmonary Dysfunction in Coalworkers' Pneumoconiosis. Br. J. Ind. Med. 38:1259 (1981).
19. Samet, J.M.; Marbury, M.C.; Spengler, J.D.: Health Effects and Sources of Indoor Pollution: Part I. Am. Rev. Respir. Dis. 136:1486–1508 (1987).
20. Samet, J.M.; Marbury, M.C.; Spengler, J.D.: Health Effects and Sources of Indoor Pollution: Part II. Am. Rev. Respir. Dis. 137:221–242 (1988).
21. Becklake, M.R.; White, N.: Sources of Variation in Spirometric Measurements. Occup. Med.: State of Art Rev. 8:241–264 (1993).