Rapid Declines in FEV_1 and Subsequent Respiratory Symptoms, Illnesses, and Mortality in Coal Miners in the United States

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Coal mine dust exposure is associated with accelerated loss of lung function. We assessed long-term health outcomes in two groups of underground coal miners who during previous mine surveys had shown either high rates of FEV_1 decline (cases, n = 310) or relatively stable lung function (referents, n = 324). Cases and referents were matched initially for age, height, smoking status, and FEV_1. We determined vital status for 561 miners, and obtained a follow-up questionnaire for 121 cases and 143 referents. Responses on the follow-up questionnaire were compared with those on the last previous mine health survey questionnaire. Cases showed a greater incidence of symptoms than did referents for cough, phlegm production, Grades II and III dyspnea, and wheezing, and greater incidences than referents of chronic bronchitis and self-reported asthma and emphysema. More cases than referents (15% versus 4%) left mining before retirement because of chest illnesses. After controls were applied for age and smoking, cases had twice the risk of dying of cardiovascular and nonmalignant respiratory diseases and a 3.2-fold greater risk of dying of chronic obstructive pulmonary disease than did referents. Rapid declines in FEV_1 experienced by some coal miners are associated with subsequent increases in respiratory symptoms, illnesses, and mortality from cardiovascular and nonmalignant respiratory diseases.

The adverse respiratory health effects of occupational dust exposure have been extensively reviewed (1, 2). Two recent comprehensive reviews of the literature, including many coal mining studies, concluded that exposure to occupational dust is a cause of chronic obstructive lung disease (3, 4).

The relationships between coal mine dust exposure and increased respiratory symptoms, deficits in lung function, and development of coal workers' pneumoconiosis are well documented (5, 6). Cumulative dust exposure has been shown to be related to reductions in FEV_1 among coal miners in the United States without radiographic evidence of pneumoconiosis, after controls were applied for age and smoking status (6). In a study of 3,380 British coal miners without documented pneumoconiosis, both smoking and coal mine dust exposure were associated not only with abnormal lung function ($FEV_1 <$ 80% predicted), but also with marked reductions in FEV_1 ($FEV_1 <$ 65% predicted) (5). Longitudinal studies in both British (7) and American coal miners (8) have reached similar results, linking estimated dust exposures with rates of FEV_1 decline. Among a group of 904 young lignite miners exposed to relatively low dust levels in a Sardinian mine, individual exposures to coal mine dust were related to rates of longitudinal decline in FVC, FEV_1, and the ratio of diffusion capacity of carbon dioxide to alveolar volume ($D_{L_{CO}}/\dot{V}_A$) during follow up, after accounting for age, smoking, and initial FVC, FEV_1, and $D_{L_{CO}}/\dot{V}_A$ levels (9).

The long-term effects of dust exposures have been extensively explored. Investigations have documented premature deaths among coal miners from nonmalignant respiratory diseases, cardiovascular disease, and cancers of the digestive tract (10–12).

The purpose of the present study was to determine the long-term health outcomes associated with rapid declines in FEV_1 observed among some underground coal miners. We evaluated respiratory symptoms, illnesses, and mortality among a group of miners who had earlier demonstrated accelerated losses of FEV_1 in the U.S. National Study of Coal Workers' Pneumoconiosis (NSCWP), in comparison with a matched referent group of miners with relatively stable lung function.

METHODS

Subjects

As previously described (13), all of our subjects were male underground coal miners who had participated in the NSCWP longitudinal cohort study. Each case miner (CS, n = 310) had shown a decline in FEV_1 of at least 60 ml/yr greater than that of a matched (age, height, smoking status, initial FEV_1) referent miner (RF, n = 324) over a previous 6- to 18-yr follow-up period that ended between 1977 and 1988. The calculation of the slope of FEV_1 for each miner was based on two measurements. No information was available on which to base an attempt to locate two of the 634 miners.

Questionnaire

Between 1994 and 1997, a period corresponding to 10 to 18 yr after the last previous health survey, we conducted a new follow-up questionnaire (FQ) survey in these miners, either by mail or telephone. The questionnaire used in this survey has been previously described (14). The following variables were analyzed in the FQ survey: (*1*) demographics, including age (at interview or date of death) and total years of schooling; (*2*) occupational history, including age at first job, age of starting mining, age of leaving mining, and reason for leaving mining; (*3*) smoking, including smoking status, whether smoke was inhaled while smoking, age at which smoking began, age at which smoking stopped, cigarettes smoked per day, pack-years smoked, and whether filtered cigarettes were used; (*4*) chest symptoms, including cough, phlegm production, dyspnea (Grades I to IV), and persistent or episodic wheezing; and (*5*) chest illnesses, defined as a "yes" response to "Have you ever had asthma/emphysema/pneumonia", or chronic bronchitis, defined as cough and phlegm production on most days for at least 3 mo each year? Analyses also considered whether asthma or emphysema was reported by the subject as having been diagnosed by a physician, and the subject's age at diagnosis. Variables related to coal mine dust exposure (mining region, tenure, years underground, years at the coal face) have been previously analyzed and reported elsewhere (14). All methods included in the protocol were approved by the National Institutes for Occupational Safety and Health Human Subjects Review Board.

Death Certificates

Serial reviews of national data bases were used to ascertain the vital status of the 634 miners studied. Information about deaths was also

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obtained through mailings and telephone calls to family members of the deceased. Copies of death certificates were obtained for all 92 of the miners known to be deceased. Causes of death (both underlying and contributing) were coded by a certified nosologist at the National Center for Health Statistics according to the eighth or ninth revision of the *International Classification of Diseases ICD-8* or *ICD-9*, respectively (15). The nosologist had no knowledge of case status or the study objectives. For the seven miners who died before June 6, 1981, causes of death were coded according to *ICD-8*. All other death certificates were coded according to *ICD-9*. The *ICD-8* codes were checked against the *ICD-9* codes for the same underlying and contributing causes of death, and were found to be similar. The ICD codes used in the definitions of cardiovascular diseases included 410, 412, 414 to 416, 425, 427, and 428. Nonmalignant respiratory diseases were identified by ICD codes 011, 486, 487, 492, 496, 500, 505, 514, 515, 518, and 519. Miners who died of either emphysema (code 492) or chronic airway obstruction (code 496) were classified as having died of chronic obstructive pulmonary disease (COPD). Causes of death were coded for malignant neoplasms of the digestive organs (151, 153, 154); trachea, bronchus, or lung (162); and other sites (197 to 199). In the analysis of deaths from cardiovascular disease, nonmalignant respiratory disease, or COPD, all deaths from the particular cause were included in the analysis, irrespective of other listed causes. Data were analyzed irrespective of whether the cause of death was listed as a primary or contributing cause.

Statistics

The Statistical Analysis System (SAS Institute Inc., Cary, NC) was used for data analyses (16). Among the 264 miners who completed the follow-up questionnaire, only 65 of the original matched-case-and-referent pairs were identified. However, when the groups of 121 CS and 143 RF miners who responded to the questionnaire were compared with the respective cohorts among the entire group of 634 miners from the NSCWP, they were found to be similar for all matched variables (age, height, smoking status, and initial FEV_1). Therefore, we decided to analyze the questionnaire and death certificate data for CS and RF by using group comparisons. We used *t* tests for continuous variables and chi-square tests for dichotomous variables when comparing grouped data for CS and RF. When making comparisons among multiple groups for continuous variables, we used analysis of variance (ANOVA) statistics.

A survival analysis, done with Cox's proportional hazards model, was used to determine the risk ratios for cardiovascular and pulmonary mortality in CS versus RF subjects, by controlling for the potentially confounding factors of age and smoking (using the SAS Proc phreg). The survival time was defined as the period from the date of the last NSCWP health survey questionnaire to death or to the end of the mortality follow-up on January 31, 1997. The case status (CS versus RF) was entered into the model as a dummy variable. The subject's age at the last health survey was added into the model in the form of a continuous variable, and smoking status at the last NSCWP survey was categorized into the two dichotomous variables of current smoker and ex-smoker. Three models were established for death, as follows: (*1*) from all causes; (*2*) from cardiovascular and nonmalignant respiratory diseases; or (*3*) from COPD. Probability levels at $p < 0.05$ were considered significant.

RESULTS

Subjects

Figure 1 shows the vital status of the 634 study miners at the time of the FQ survey. Of the total, 73 individuals (37 CS and 36 RF) were lost to follow-up. Of the remaining 561 miners, 92 (53 CS and 39 RF) were deceased and 469 were still living. A total of 264 (121 CS and 143 RF) FQ were completed by either the miner (91%) or an immediate family member (9%) if the miner was deceased. The groups of CS and RF miners with completed FQ were compared (15). Among the FQ respondents, CS and RF miners were similar for initial age, height, and FEV_1. For both the initial and final NSCWP surveys, the proportions of current, ex-, and never smokers were similar for the CS and RF groups.

Responses to the FQ showed that at the time of interview or date of death, CS and RF miners were also similar for age, marital status, age at first job, age at first coal job, and total years of schooling (Table 1). The proportions of never-, ex-, and current smokers, and of mean pack-years smoked, were also similar for the CS and RF groups. A similar proportion of CS and RF smokers had quit smoking since the final NSCWP coal mine survey. For those miners who had ever smoked, there were no differences between the CS and RF groups with regard to inhaling cigarette smoke or smoking cigarettes with a filter tip (data not shown).

Reasons for Leaving Coal Mining

A higher proportion of CS (87%) than of RF (76%) miners had left mining at the time of the interview ($p < 0.05$), although the age at which miners in the two groups left the coal industry was similar (53.9 yr versus 52.6 yr). Reasons associ-

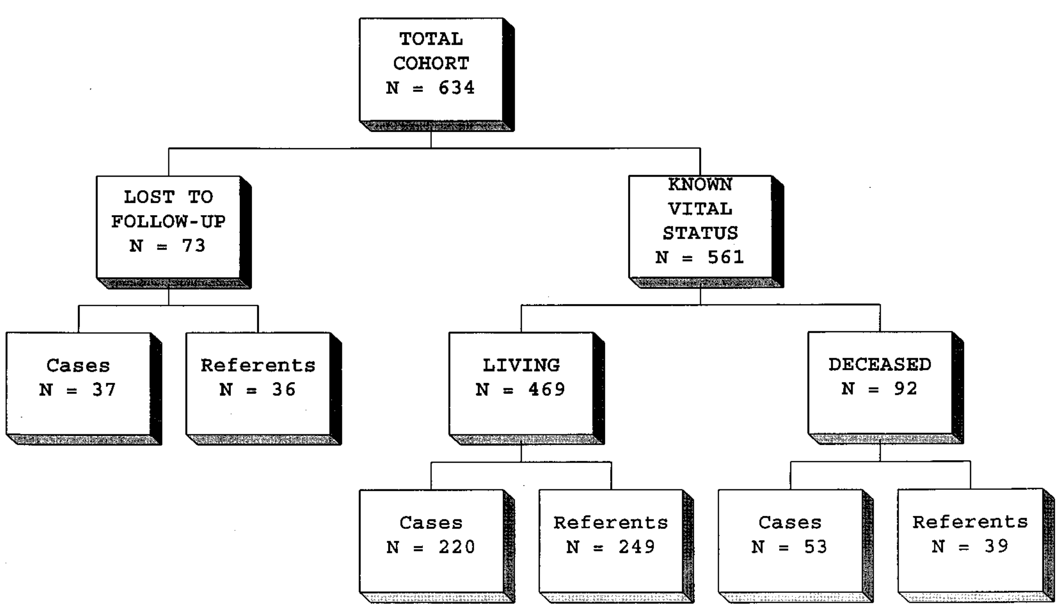

Figure 1. Vital status at time of the follow-up questionnaire for original cohort of 634 miners.

TABLE 1. CHARACTERISTICS OF CASES AND REFERENTS BASED ON FOLLOW-UP QUESTIONNAIRE*

	Cases (*n* = 121)	Referents (*n* = 143)
Age, yr†	61.4 (9.4)	60.0 (9.9)
Vital status		
Alive, n (%)	109 (90.1)	132 (92.3)
Deceased, n (%)	12 (9.9)	11 (7.7)
Marital status†		
Married, n (%)	113 (94.2)	137 (96.5)
Single, n (%)	7 (5.8)	8 (3.5)
Total years of schooling	11.0 (2.4)	11.0 (2.6)
Age at first job, yr	17.5 (2.0)	17.7 (1.9)
Age at first coal job, yr	22.9 (6.6)	23.4 (6.2)
Age when left coal industry, yr	53.9 (9.0)	52.6 (10.0)
Smoking, pack yr	24.2 (24.1)	21.3 (19.5)
Smoking status:†		
Never smoker, n (%)	30 (24.8)	42 (29.4)
Ex-smoker, n (%)	61 (50.4)	68 (47.6)
Current smoker, n (%)	30 (24.8)	33 (23.1)

* Values are mean ± SD.
† At time of interview or date of death.

ated with an individual miner's leaving the coal mining industry are shown in Table 2. As compared with RF miners, a higher proportion of CS miners left coal mining before retirement because of chest/lung illnesses. Leaving mining through regular retirement, because of mine closure or as a result of being fired, taking another job outside of coal mining, injury, or heart illnesses each affected similar proportions of the CS and RF groups.

Chest Symptoms and Illnesses

Table 3 shows comparisons of incidences of respiratory symptoms and chest illnesses reported at the time of the FQ survey since those in the last NSCWP survey. The interval between the final NSCWP survey and the FQ survey was similar for the CS and RF groups (mean = 12 yr, p = 0.91). The CS group had higher incidences than the RF group of cough, phlegm production, Grade II dyspnea, Grade III dyspnea, wheezing, episodic wheezing, persistent wheezing, and wheezing with shortness of breath.

Incidences of chest illnesses since the last NSCWP survey are also shown in Table 3. There were higher incidences for the CS than for the RF group for bronchitis, self-reported asthma, and emphysema.

Mortality

The original study cohort contained 634 miners. We were unable to confirm the vital status of 73 individuals. Of the remaining 561 miners, 92 were deceased and 469 were alive at the time of our study.

TABLE 2. REASONS ASSOCIATED WITH A MINER LEAVING THE COAL MINING INDUSTRY, BASED ON FOLLOW-UP QUESTIONNAIRE

Reason for Leaving Mining	Cases (*n* = 105)	Referents (*n* = 108)
Regular retirement	21 (20.0)*	27 (25.0)
Mine closure/fired	43 (41.0)	39 (36.1)
Other job outside mining	2 (1.9)	4 (3.7)
Injury	14 (13.3)	16 (14.8)
Chest/lung illness	18 (17.1)	6 (5.6)†
Heart illness	4 (3.8)	4 (3.7)
Other illnesses	3 (2.9)	12 (11.1)

* Values are number (%).
† $p < 0.02$.

TABLE 3. CUMULATIVE INCIDENCES OF RESPIRATORY SYMPTOMS AND CHEST ILLNESSES FROM THE FINAL NATIONAL STUDY OF COAL WORKERS' PNEUMOCONIOSIS SURVEY TO THE FOLLOW-UP QUESTIONNAIRE*

	Symptom or Illness Absent at Last Survey (*n*)	Cumulative Incidence, n/N† (%)		
		Cases	Referents	p Value
Cough	151	24/58 (41.4)	22/93 (23.7)	0.021
Phlegm production	144	30/62 (48.4)	19/82 (23.2)	0.002
Dyspnea				
Grade II	176	41/76 (54.0)	31/100 (31.0)	0.002
Grade III	218	42/96 (43.8)	28/122 (23.0)	0.001
Wheezing (ever)	103	23/41 (56.1)	22/62 (35.5)	0.039
Episodic	215	17/91 (18.7)	10/124 (8.1)	0.020
Persistent	162	27/63 (42.9)	24/99 (24.2)	0.013
Wheezing with shortness of breath	198	37/79 (46.8)	21/119 (17.7)	0.001
Pneumonia	208	18/92 (19.6)	15/116 (12.9)	0.193
Bronchitis	175	31/76 (40.8)	23/99 (23.2)	0.013
Asthma	254	6/114 (5.3)	1/140 (0.7)	0.048‡
Emphysema	246	18/107 (16.8)	9/139 (6.5)	0.010

* Interval between final survey in U. S. National Study of Coal Workers' Pneumoconiosis (NSCWP) and follow-up questionnaire for case miners and referent miners was similar (mean 12 yr, p = 0.910).
† N = symptom/illness absent at final NSCWP survey; n = symptom/illness present at follow-up questionnaire. (%): Cumulative incidence from final NSCWP survey to follow-up questionnaire. Note: the final NSCWP health surveys were conducted between 1977 and 1988, the follow-up questionnaire was administered between 1994 and 1997.
‡ Fisher's exact test (two-tailed).

Table 4 compares characteristics of the CS and RF groups at the last NSCWP survey by follow-up vital status. Age, height, and pack-years smoked were similar at the two groups' last NSCWP survey within the vital-status categories used in the study. The RF group weighed less than the CS group miners at their last NSCWP health survey for those miners still alive at the time of the FQ survey. CS miners had significantly lower values of FEV_1 and FVC, and of the FEV_1/FVC ratio than did their respective RF counterparts for those miners who were lost to follow-up, alive at the time of the FQ survey, and deceased at the time of the FQ survey. Deaths were somewhat more common among the CS (53 of 273) than among the RF (39 of 288) miners ($p < 0.06$). Among the CS miners who were never-smokers at their last NSCWP health survey, 20% (13 of 65) died, versus 7% (five of 68, $p < 0.05$) of the RF miners.

Average age at death was similar for the CS and RF groups (62 yr). There were a total of 248 underlying and contributing causes of death identified on the 92 death certificates. Each deceased miner had one underlying cause of death. The number of contributing causes of death per miner ranged from 0 to 6, with a mean of 2.7 causes. Comparisons of underlying and other causes of death by vital status are shown in Table 5. A higher proportion of CS (37 of 273, 13.6%) than of RF (20 of 288, 6.9%) miners ($p < 0.01$) died of cardiovascular or nonmalignant respiratory disease.

Table 6 shows the annual rate of decline (slope) in FEV_1, FVC, and the FEV_1/FVC ratio obtained from the NSCWP longitudinal lung function studies for CS and RF miners, categorized by the subsequent follow-up vital status. Case subjects who died had significantly greater rates of decline in both FEV_1 and FEV_1/FVC ratio than did case subjects who were alive or lost to follow-up.

Average annual rates of decline in FEV_1 were greater for CS than for RF miners among miners who, at the time of the

TABLE 4. CHARACTERISTICS OF CASES AND REFERENTS BY FOLLOW-UP VITAL STATUS BASED ON THE LAST NATIONAL STUDY OF COAL WORKERS' PNEUMOCONIOSIS SURVEY*

		Lost to Follow-Up		Alive		Deceased	
		Cases (n = 37)	Referents (n = 36)	Cases (n = 220)	Referents (n = 249)	Cases (n = 53)	Referents (n = 39)
Age, yr	Mean	44.4	45.7	48.5	48.2	53.5	53.7
	SD	9.0	8.5	8.7	8.8	7.4	7.5
Height, cm	Mean	176.5	176.3	176.3	175.8	175.3	176.5
	SD	6.86	5.84	6.35	6.35	7.37	6.10
Weight, kg	Mean	87.5	84.0	87.6	82.9†	83.5	83.6
	SD	15.7	11.4	16.1	11.5	21.4	13.6
Smoking, pack-years	Mean	16.1	17.9	18.5	16.7	22.5	22.1
	SD	14.0	21.3	16.5	16.1	17.9	17.2
FEV_1, L	Mean	3.11	4.04‡	2.91	3.86‡	2.46	3.41‡
	SD	0.63	0.69	0.73	0.68	0.91	0.57
FVC, L	Mean	4.25	5.16‡	4.12	5.00‡	3.79	4.59†
	SD	0.72	0.76	0.86	0.81	1.05	0.87
FEV_1/FVC (%)	Mean	73.3	78.2*	71.1	77.2‡	64.4	74.8‡
	SD	8.9	6.5	11.6	6.0	14.0	6.3

* n = 634, consisting of 310 cases and 324 referents.
† $p < 0.01$ for cases versus referents.
‡ $p < 0.001$ for cases versus referents.
§ $p < 0.0001$ for cases versus referents.

follow up study, were alive (−92 ml/yr versus −5 ml/yr), had died of cardiovascular or nonmalignant respiratory disease (−109 ml/yr versus −8 ml/yr), and had died of COPD (−118 ml/yr versus −18 ml/yr).

Table 7 shows results from the Cox proportional hazards analyses of the main effects of the factors studied. After adjustment for age and smoking, the relative risk estimates imply that a coal miner with a rapid decline in FEV_1 over an average period of 11 yr (defined in this study as a case) would have twice the risk of dying of cardiovascular or nonmalignant respiratory disease, and a 3.2-fold greater risk of dying of COPD, than would a miner with a stable FEV_1 over a similar follow-up period (i.e., classified as a referent); these associations were statistically significant. Age and current smoking status at the last NSCWP survey were also significantly associated with increased mortality.

DISCUSSION

To better understand the potential consequences of the accelerated losses of lung function observed among some coal miners, we investigated symptoms, illnesses, and vital status among two groups of coal miners 19 to 28 yr after they had first participated in a mine health survey. Our results indicated that the group of miners who had shown accelerated loss of lung function during their mining careers subsequently experienced significantly more symptoms of cough, phlegm production, wheezing, and high grades of dyspnea than did their colleagues with more stable lung function. Asthma, chronic bronchitis, and emphysema, including illnesses reported as having been diagnosed by a physician, were reported more commonly at follow-up by miners with rapid delines in FEV_1. In addition to experiencing respiratory tract symptoms and illnesses, miners with steeper losses of lung function were more likely to retire from mining because of chest illnesses, and were also at significantly higher risk of death from cardiovascular or nonmalignant respiratory disease.

TABLE 5. COMPARISONS OF UNDERLYING AND OTHER CAUSES OF DEATH BY CASE STATUS*

	Cases	Referents	Total
Status	n (%)	n (%)	n (%)
Alive	220 (80.6)	249 (86.5)	469 (83.6)
Deceased			
All causes	53 (19.4)	39 (13.5)	92 (16.4)
Cardiovascular†	27 (9.9)	15 (5.2)	42 (7.5)
Pulmonary			
COPD†	12 (4.4)	4 (1.4)	16 (2.9)
Non-COPD	16 (5.9)	9 (3.1)	25 (4.5)

Definition of abbreviation: COPD = chronic obstructive pulmonary disease.
* From *International Classification of Diseases* (ICD-9).
† $p < 0.05$ for cases versus referents.

Our study found that miners who had experienced high rates of decline in FEV_1 during their working careers subsequently reported greater rates of onset of several respiratory tract symptoms and illnesses. Many previous cross-sectional studies have associated a reduced level of FEV_1 with respiratory tract symptoms and other adverse health outcomes (17), although longitudinal relationships between changes in ventilatory function and symptoms have not been as well studied. Brodkin and colleagues reported a 3- to 5-yr longitudinal study of symptoms and spirometry in 446 asbestos-exposed workers (18). In their study, development of any of the cardinal symptoms (cough, phlegm production, wheezing, and dyspnea) was associated with an increased rate of concurrent decline in FEV_1. In contrast, symptoms present at the initial survey were associated with a subsequent decline in FEV_1/FVC ratio, but not in FEV_1. In a group of 346 French dairy farmers, persistence or emergence of chronic bronchitis, and also of dyspnea, was associated with excess ventilatory decline over a period of 6 yr (19). Among male grain elevator workers participating in a mandated health surveillance program, onset or persistence of wheezing was associated with a significantly increased annual decline in FEV_1 over a period of 8.6 yr (20). Sharp and colleagues assessed symptoms and spirometry over a 7-yr period in a group of 1,263 workers, and noted that declines in the FEV_1/FVC ratio were more prevalent among workers who had persistent symptoms of cough, phlegm production, and dyspnea, or who reported the onset of wheezing (21). Analyses of community-based studies suggest that initial respiratory symptoms predict only a slightly greater risk of progressive airflow limitation (22), whereas accelerated loss of FEV_1 is more commonly found among persons with persistent or newly devel-

TABLE 6. ANNUAL RATE OF DECLINE (SLOPE) IN SPIROMETRY INDICES FOR CASES AND REFERENTS BY FOLLOW-UP VITAL STATUS

		Cases (*n* = *310*)			Referents (*n* = *324*)		
		Lost to follow-up (*n* = *37*)	Alive (*n* = *220*)	Deceased (*n* = *53*)	Lost to follow-up (*n* = *36*)	Alive (*n* = *249*)	Deceased (*n* = *39*)
Interval, yr*	Mean	11.2	11.7	11.0	11.8	11.8	10.2†
	SD	2.9	2.8	3.4	2.7	2.9	2.5
FEV_1, ml/yr	Mean	−87.0	−91.9	−106.5†	−2.90	−4.8	−7.9
	SD	32.7	30.5	29.8	33.0	24.2	22.3
FVC, ml/yr	Mean	−101.7	−103.5	−111.7	−0.5	−16.6	−22.2
	SD	52.5	49.8	49.3	41.4	35.4	42.8
FEV_1/FVC, %/yr	Mean	−0.25	−0.33	−0.72‡	0.03	0.15	0.17
	SD	0.71	0.65	0.86	0.57	0.50	0.47

* Interval during National Study of Coal Workers' Pneumoconiosis over which spirometry declines were calculated.
† $p < 0.01$ (deceased versus lost and alive within cases and referents).
‡ $p < 0.001$ (deceased versus lost and alive within cases and referents).

oped symptoms (23). The findings of the present study are consistent with these previous reports. Additionally, because of its design, our study extends these findings by providing evidence that rapid declines in FEV_1 may become apparent even before the reporting of respiratory symptoms and illnesses.

According to the Cox proportional hazards models, deaths from cardiovascular and nonmalignant respiratory diseases, and deaths from COPD, were significantly more common among the miners in our study who had previously experienced accelerated declines in FEV_1. The mean FEV_1 levels for CS and RF miners were very similar at their initial health surveys (14). Thus, the current findings provide evidence that, in addition to FEV_1 level, accelerated declines in lung function are an indicator of increased risk of death. The relationship between FEV_1 level and subsequent mortality has been observed in a number of community-based studies (24, 25). Impairments of lung function were also found to have increased the risk of mortality from COPD among coal miners as well, and respiratory symptoms heralded an increased risk of subsequent mortality from nonmalignant respiratory diseases (26). However, only a few previous studies have investigated the importance of longitudinal change in ventilatory function with regard to subsequent mortality. Rapid declines in FEV_1 have been noted to presage mortality from heart disease (27, 28). In a follow-up study of 1,691 persons in the Busselton (Australia) Health Study, Ryan and colleagues observed that decline in lung function was a predictor of death from cardiovascular disease and from all causes, independent of average FEV_1 level and other risk factors (29). The current investigation strengthens the evidence from these previous studies that rapid longitudinal decline in FEV_1 is associated with subsequent mortality, and highlights an association with mortality from COPD.

The results of this study document the potential consequences of rapid declines in lung function, and emphasize the importance of recognition and effective interventions for individuals who experience accelerated losses of FEV_1. By demonstrating that lung functional declines can often be documented before symptoms and illnesses are reported, the findings of the present study increase the plausibility that medical monitoring programs can be important components of an effective lung disease prevention strategy. Studies of the natural history of chronic airflow obstruction have previously shown that for individuals with accelerated losses of lung function, exposure control (e.g., engineering controls, smoking cessation) does not generally result in an improvement in FEV_1, but rather a return to the age-appropriate rates of decline (30, 31). Thus, the risks of illness and premature death among workers exposed to respiratory hazards are more likely to be reduced when accelerated loss of FEV_1 is recognized early and exposures promptly controlled (32).

Our study had several limitations. First, although ascertainment of vital status was available for 88% of the cohort, the questionnaire follow-up was less complete. The group of miners that completed the questionnaire may not have been fully representative of the entire cohort. It is possible that reduced participation significantly biased the subsequent morbidity reported here. However, there is evidence that the health of study participants may be better than that of nonparticipants

TABLE 7. SURVIVAL ANALYSES RESULTS USING COX'S REGRESSION MODEL

	Model 1 (Death n = 92, Censored n = 469)*		Model 2 (Death n = 57, Censored n = 504)†		Model 3 (Death n = 16, Censored n = 545)‡	
Variable	Coefficient (SE)	Risk Ratio (p Value)	Coefficient (SE)	Risk Ratio (p Value)	Coefficient (SE)	Risk Ratio (p Value)
Age, yr	0.077	1.080	0.090	1.094	0.117	1.124
	(0.015)	(0.0001)	(0.019)	(0.0001)	(0.039)	(0.0027)
Current smoker (1,0)	0.757	2.132	0.738	2.093	2.208	9.096
	(0.272)	(0.0055)	(0.333)	(0.0265)	(1.036)	(0.0330)
Ex-smoker (1,0)	−0.525	0.591	−1.115	0.328	−15.484	0.000
	(0.365)	(0.1504)	(0.533)	(0.0366)	(2.071)	(0.9940)
Case status (1,0)	0.371	1.449	0.728	2.072	1.162	3.196
	(0.211)	(0.0791)	(0.278)	(0.0087)	(0.578)	(0.0443)

* Model 1 for death from all causes.
† Model 2 for death from cardiovascular and non-malignant respiratory diseases.
‡ Model 3 for death with COPD.

(33), and it seems unlikely that in the case of our study, the development of symptoms and illnesses among the nonparticipant cases was sufficiently disparate from that among the nonparticipant referents that full participation would have nullified the overall results. Second, the CS and RF miners examined in the study were identified among the 5,900 miners who had participated in the longitudinal cohort of the NSCWP. This study cohort may not have been entirely representative of the overall population of active underground coal miners in the United States. The NSCWP miners worked predominantly at larger mines, which may present a lower risk for occupational illnesses than do smaller mines. Lynch (34) reported that underground bituminous coal mines with fewer than 10 workers accounted for 11% of all reported cases of respiratory dust disease, while accounting for only 1.7% of working hours in mines. A review of chest X-ray B-readings for coal miners with 20 or more years of underground experience revealed that a higher proportion (20.5%) of those who worked in small mines (fewer than 20 workers) had Category 1/1 or greater than did miners (17%) working in larger mines (100 or more workers).

These factors may have affected the overall patterns of morbidity and mortality that were observed in our study. However, it seems unlikely that a larger sample, including more small mines, would have affected the conclusion that coal miners with clinically significant losses of lung function are at greater risk for developing respiratory tract symptoms and illnesses, and for premature death from cardiovascular or nonmalignant respiratory disease, particularly COPD, than are miners without such losses.

The information available from this study does not contain sufficient detail to permit a full reconstruction of the chronologic relationships among declines in lung function, development of symptoms, and establishment of lung disease in the miners that we studied. Since the participants had only two to four spirometry tests over a period of 6 to 18 yr, these data cannot indicate how early the declines that we observed would become apparent with regular testing. There is also evidence that occupational losses in FEV_1 may not follow a linear pattern over time (35). Future investigations may need to address the efficiency of different strategies for early detection of excessive losses of lung function. Furthermore, although our study was performed among coal miners, dust-related losses of lung function have been observed in other occupations (3), and similarly affected workers in other industries may have a similar potential for development of respiratory symptoms, illnesses, and mortality.

Summary

We followed a select group of underground coal miners longitudinally. Both never-smoking and smoking miners who experienced accelerated declines in FEV_1 subsequently developed more frequent respiratory symptoms and chest illnesses than those who did not experience such declines. They were also at significantly greater risk of death from cardiovascular or nonmalignant respiratory disease than were their colleagues with more stable lung function. These findings support the potential efficacy of medical screening with spirometry among dust-exposed workers for identifying individuals with rapid losses of lung function and to allow targeted early interventions to preserve lung function.

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References

1. Korn RJ, Dockery DW, Speizer FE, Ware JH, Ferris BG. Occupational exposures and chronic respiratory symptoms: a population-based study. *Am Rev Respir Dis* 1987;136:298–304.
2. Becklake MR. Chronic airflow limitation: its relationship to work in dusty occupations. *Chest* 1985;88:608–617.
3. Oxman AD, Muir DC, Shannon HS, Stock SR, Hnizdo E, Lange HJ. Occupational dust exposure and chronic obstructive pulmonary disease: a systematic overview of the evidence. *Am Rev Respir Dis* 1993; 148:38–48.
4. Coggon D, Taylor AN. Coal mining and chronic obstructive lung disease: a review of the evidence. *Thorax* 1988;53:398–407.
5. Marine WM, Gurr D, Jacobsen M. Clinically important respiratory effects of dust exposure and smoking in British coal miners. *Am Rev Respir Dis* 1988;137:106–112.
6. Attfield MD, Hodous TK. Pulmonary function of U.S. coal miners related to dust exposure estimates. *Am Rev Respir Dis* 1992;145:605–609.
7. Love RG, Miller BG. Longitudinal study of lung function in coal-miners. *Thorax* 1982;37:193–197.
8. Attfield MD. Longitudinal declines in FEV_1 in United States coal miners. *Thorax* 1985;40:132–137.
9. Carta P, Aru G, Barbier MT, Avataneo G, Casula D. Dust exposure, respiratory symptoms, and longitudinal decline of lung function in young coal miners. *Occup Environ Med* 1996;53:312–319.
10. Rockette HE. Cause specific mortality of coal miners. *J Occup Med* 1977; 19:795–801.
11. Miller BG, and Jacobsen M. Dust exposure, pneumoconiosis, and mortality of coal miners. *Br J Ind Med* 1985;42:723–733.
12. Meijers JM, Swaen GM, Slangen JJ, van Vliet K, Sturmans F. Long-term mortality in miners with coal workers' pneumoconiosis in the Netherlands: a pilot study. *Am J Ind Med* 1991;19:43–50.
13. Wang ML, Petsonk EL, Attfield MD, Short SR, Beeckman LF, Bonnett B, Hankinson JL. Miners with clinically important declines in FEV_1: analysis of data from the U.S. National Coal Study. *Appl Occup Environ Hyg* 1996;11:989–995.
14. Wang ML, Petsonk EL, Beeckman LF, Wagner GR. Clinically important FEV_1 declines among coal miners: an exploration of previously unrecognized determinants. *Occup Environ Med* 1999;56:837–844.
15. World Health Organization. Manual of the international statistical classification of diseases, injuries, and causes of death. In: International classification of diseases, 9th ed. Geneva, Switzerland: World Health Organization; 1978.
16. SAS Institute Inc. SAS procedures guide, version 6, 3rd ed. Cary, NC: SAS Institute; 1990.
17. Brodkin CA, Rosenstock L. The relation between chronic respiratory symptoms and ventilatory capacity in adults. *Occup Med* 1993;8:363–374.
18. Brodkin CA, Barnhart S, Checkoway H, Balmes J, Omenn GS, Rosenstock L. Longitudinal pattern of reported respiratory symptoms and accelerated ventilatory loss in asbestos-exposed workers. *Chest* 1996;109: 120–126.
19. Dalphin JC, Maheu MF, Dussaucy A, Pernet D, Polio JC, Dubiez A, Laplante JJ, Depierre A. Six year longitudinal study of respiratory function in dairy farmers in the Doubs province. *Eur Respir J* 1996;11: 1287–1293.
20. Senthilselvan A, Pahwa P, Wang P, McDuffie HH, Dosman JA. Persistent wheeze in grain elevator workers should not be ignored. *Am J Respir Crit Care Med* 1996;153:701–705.
21. Sharp JT, Paul O, McKean H, Best WR. A longitudinal study of bronchitic symptoms and spirometry in a middle-aged, male, industrial population. *Am Rev Respir Dis* 1973;108:1066–1077.
22. Sherman CB, Xu X, Speizer FE, Ferris BG Jr, Weiss ST, Dockery DW. Longitudinal lung function decline in subjects with respiratory symptoms. *Am Rev Respir Dis* 1992;146:855–859.
23. Vestbo J, Prescott E, Lange P. Association of chronic mucus hypersecretion with FEV_1 decline and chronic obstructive pulmonary disease morbidity: Copenhagen City Heart Study Group. *Am J Respir Crit Care Med* 1996;153:1530–1535.
24. James AL, Knuiman MW, Divitini ML, Musk AW, Ryan G, Bartholomew HC. Associations between white blood cell count, lung function, respiratory illness and mortality: the Busselton Health Study. *Eur Respir J* 1999;13:1115–1119.
25. Weiss ST, Segal MR, Sparrow D, Wager C. Relation of FEV_1 and peripheral blood leukocyte count to total mortality: the Normative Aging Study. *Am J Epidemiol* 1995;142:493–498.
26. Meijers JM, Swaen GM, Slangen JJ. Mortality of Dutch coal miners in relation to pneumoconiosis, chronic obstructive pulmonary disease, and lung function. *Occup Environ Med* 1997;54:708–713.
27. Tockman MS, Pearson JD, Fleg JL, Metter EJ, Kao SY, Rampal KG, Cruise LJ, Fozard JL. Rapid decline in FEV_1: a new risk factor for

coronary heart disease mortality. *Am J Respir Crit Care Med* 1995; 151:390–398.

28. Rodriguez BL, Masaki K, Burchfiel C, Curb JD, Fong K-O, Chyou P-O, Marcus EB. Pulmonary function decline and 17-year total mortality: the Honolulu Heart Program. *Am J Epidemiol* 1994;140:398–408.
29. Ryan G, Knuiman MW, Divitini ML, James A, Musk AW, Bartholomew HC. Decline in lung function and mortality: the Busselton Health Study. *J Epidemiol Commun Health* 1999;53:230–234.
30. Camilli AE, Burrows B, Knudson RJ, Lyle SK, Oebowitz MD. Longitudinal changes in forced expiratory volume in one second in adults—effects of smoking and smoking cessation. *Am Rev Respir Dis* 1987; 135:794–799.
31. Xu X, Dockery DW, Ware JH, Speizer FE, Ferris BG. Effects of cigarette smoking on rate of loss of pulmonary function in adults: a longitudinal assessment. *Am Rev Respir Dis* 1992;146:1345–1348.
32. Hankinson JL, Wagner GR. Medical screening using periodic spirometry for detection of chronic lung disease. In: Eisen EA, editor. Occupational medicine: State of the Art reviews, vol. 8. Philadelphia: Hanley & Belfus; 1993. p. 353–361.
33. Petersen M, Attfield M. Estimates of bias in a longitudinal coal study. *J Occup Med* 1981;23:44–48.
34. Linch KD. Environmental surveillance of small coal mines: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Beckley, WV: Unpublished report, presented at the Small Mines Summit (April, 1994); 1997.
35. Seixas NS, Robins TG, Attfield MD, Moulton LH. Longitudinal and cross sectional analyses of exposure to coal mine dust and pulmonary function in new miners. *Br J Ind Med* 1993;50:929–937.