Clinically important FEV₁ declines among coal miners: an exploration of previously unrecognised determinants

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Abstract

Objectives—The relation between occupational exposure to dust and loss of ventilatory lung function is now well established. However, many exposures during work and other activities might also have important roles in determining clinically important losses of lung function. In this study, we attempted to explore additional plausible determinants of exposures and other potential risk factors for clinically important decline in forced expiratory volume in 1 second (FEV₁) during work in dusty trades.

Methods—The study was performed in 264 underground coal miners whose lung function had been followed up for an average of 11 years. With an extensive follow up questionnaire, miners were asked about their occupational and non-occupational exposures, smoking, personal and family medical history, and living conditions during childhood.

Results—Several variables of the mine environment (as well as previously recognised effects of mining work and region) were found to be associated with excess decline in FEV₁, including work in roof bolting, exposure to explosive blasting, and to control dust spraying water that had been stored in holding tanks. Use of respiratory protection seemed to reduce the risk of decline in FEV₁. Other factors that were found to be associated with declines in pulmonary function included smoking, body mass, weight gain, childhood pneumonia, and childhood exposure in the home to passive tobacco smoke and possibly smoke due to wood and coal fuels. Miners with excessive decline in FEV₁ were less likely to be working in mining jobs at follow up.

Conclusions—These findings suggest the existence of additional risk factors for decline in lung function in dusty trades, and may be useful in developing additional approaches to the prevention of chronic respiratory disease.

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Keywords: longitudinal studies; forced expiratory volume; coal mining

The association between occupational exposure to dust and loss of ventilatory lung function is supported by numerous scientific studies, and is accepted as causal by most

authorities.¹ However, it remains unclear from an occupational health viewpoint why only certain workers have accelerated rates of decline.²⁻⁶

In this study, we sought to better understand why some miners have severe declines in forced expiratory volume in one second (FEV₁) by examining potential risk factors other than those previously investigated (smoking and exposure to dust). With information obtained from an extensive new follow up questionnaire, we explored plausible alternative determinants of decline in lung function in a group of coal miners. To do this, we evaluated associations between various candidate risk factors, including occupational, environmental, and personal exposures, and clinically important decline in FEV₁, in a group of underground coal miners whose lung function had been followed up for an average 11 years. Miners, or their next of kin, if dead, were contacted by telephone, and were queried extensively about specific job activities and working conditions, mine characteristics, use of personal respiratory protection, exposures not related to work from hobbies or indoor air pollution, family and childhood medical and living conditions, and personal smoking and health histories.

Methods

SUBJECTS

The investigation was based on participants in the National Institute for Occupational Safety and Health (NIOSH) United States national study of coal workers' pneumoconiosis, which comprised a total of four rounds of radiographic, spirometric, and questionnaire surveys. A group of 310 underground coal miners with clinically important declines in FEV₁ were identified as cases, and their matched partners with stable lung function (n=324) served as referents. Subject selection, matching criteria, spirometry procedures, and the quality assessment of spirometry performance have been described in detail elsewhere.⁷ Briefly, male miners with at least 6 years of follow up between any two surveys, and whose smoking status remained the same at both (n=5900) were grouped into strata based on (a) survey, (b) age (5 year intervals), (c) height (4 cm intervals), (d) initial FEV₁ (500 ml intervals), and (e) smoking status (current, former, or non-smokers). From the miners within each stratum (matched for all five criteria), pairs of miners were selected whose annual rate of decline in FEV₁ differed by more than 60 ml/year. After a pair of miners was selected,

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Table 1 Comparison of demographic variables and spirometry indices between study subjects and non-participants from the original cohort by case status and survey (n=634)

	Cases (n=310, mean (SD))		Referents (n=324, mean (SD))	
	Participants n=121	Non-participants n=189	Participants n=143	Non-participants n=181
Age (y):				
Initial	38.0 (9.6)	36.9 (9.9)	36.3 (9.3)	37.6 (9.8)
Final	49.6 (8.5)	48.3 (9.1)	48.1 (8.6)	49.0 (9.0)
Height (inch):				
Initial	69.1 (2.3)	69.4 (2.7)	68.8 (2.6)	69.3 (2.2)
Final	69.2 (2.3)	69.4 (2.8)	68.9 (2.7)	69.4 (2.3)
Weight (lb):				
Initial	180 (28)	176 (33)	174 (27)	181 (27)
Final	191 (34)	191 (40)	179 (24)	185 (27)
Smoke (pack-years):				
Initial	15.4 (15.4)	13.5 (13.3)	11.3 (11.4)	12.9 (13.4)
Final	19.1 (18.0)	18.8 (15.6)	17.4 (16.0)	17.5 (17.5)
Underground face (y):				
Initial	5.8 (8.5)	5.4 (7.9)	4.3 (7.0)	5.2 (7.5)
Final	7.2 (9.0)	7.3 (9.1)	5.8 (8.4)	7.5 (9.2)
FEV ₁ (l):				
Initial	3.87 (0.65)	3.95 (0.74)	3.82 (0.69)	3.92 (0.64)
Final	2.82 (0.68)	2.88 (0.83)	3.76 (0.71)	3.87 (0.67)
Slope	-90.9 (29)	-95.7 (32)	-4.8 (26)	-3.9 (25)
FVC (l):				
Initial	5.22 (0.77)	5.28 (0.80)	5.07 (0.88)	5.18 (0.80)
Final	4.08 (0.85)	4.06 (0.92)	4.90 (0.88)	5.02 (0.78)
Slope	-97.5 (42)	-109.3 (54)	-14.6 (34)	-16.2 (40)
Smoking (n (%)):				
Current smoker	64 (52.9)	110 (58.2)	83 (58.0)	98 (54.1)
Ex-smoker	26 (21.5)	39 (20.6)	24 (16.8)	43 (23.8)
Never smoker	31 (25.6)	40 (21.2)	36 (25.2)	40 (22.1)

they were removed from the strata and the selection procedure repeated, until no more pairs could be selected. This selection process resulted in a total of 374 pairs of observations. However, because some miners participated in several surveys, the 374 pairs represented only 685 distinct people, 49 miners were selected twice and seven miners three times. Removal of 30 pairs based on quality of spirometry tests left 344 pairs of observations eligible for analysis, including 634 individual miners.

Between 1994 and 1997, about 10 to 18 years after the last health survey, we conducted a new follow up questionnaire survey in these miners. To locate the miners, we reviewed a series of national databases, and contacted miners or their families by post and telephone calls. Seventy three people were lost to follow up. Of the remaining 561 miners, 92 were dead and 469 were alive. A follow up questionnaire was obtained from 264 of the remaining miners (121 cases, 143 referents). The present report is based on the new information about these miners obtained from this follow up questionnaire.

QUESTIONNAIRE

Either the miner (91%), or if the miner was dead, a family member (9%) answered the questions by post or by telephone interview. Informed consent was obtained from all respondents. Questionnaire items included information about the worker's occupation and exposures not related to work, smoking, personal and family medical history, and living conditions during childhood. Respiratory health questions were drawn from the British Medical Research Council questionnaire used in the original coal mine surveys.³ Information requested on working conditions and personal work practices, mine characteristics, and family and childhood medical history was much more

detailed compared with that obtained from previous mine health surveys.

DATA ANALYSIS

Group comparisons

Of the 634 miners in the original cohort, 264 (41.6%) miners completed the follow up questionnaire. Univariate comparisons of characteristics between participants and non-participants indicated that current study subjects were a representative subset of the original matched group of subjects (table 1). These 264 miners were either cases (n=121) or referents (n=143) from the original pairs selected, but included only 65 of the original 344 matched pairs, comprising 123 people (seven miners were selected twice). In an attempt to use data for all 264 miners, instead of a matched pair analysis we used group comparison for this analysis. For comparisons of frequencies, χ^2 tests with correction for continuity were used, and for continuous variables, t tests were generally performed. However, when there were many zero values for a continuous variable, it was treated as categorical (present or absent), and the Mantel-Haenszel χ^2 test was used. Differences for which $p \leq 0.05$ were considered significant.

To investigate potential determinants of decline in lung function, cases and referents were compared for coal mining exposure (duration of mining work, average hours worked a week, duration of lay off periods), use of personal respiratory protection, mine characteristics (coal seam height and mine size), job categories, water sources in the mine, and mining practices including exposure to shotfiring (explosive blasting). All variables related to mining exposure were divided into two periods—the first before, and the second after, the final mine health survey. As spirometry results were only obtained at the mine health surveys, exposures related to mining that occurred after the time of the final mine survey were not considered in the analysis of the decline in lung functions. Comparisons were also made on demographic variables, smoking and pack-years, family and personal medical history, childhood living conditions, passive smoking and other domestic exposures, and exposures from non-mining jobs or activities not related to work. Differences between cases and referents were sought that might represent plausible determinants of the differences found in rates of decline in lung function.

Use of respiratory protection was estimated in three ways: the overall time weighted mean percentage time wearing a respirator, the maximum percentage time wearing a respirator on all jobs, and the sum of the number of years in each mining job multiplied by the percentage of time a respirator was worn on that job (%-years).

Several variables for exposure to shotfiring activity were investigated: firstly, the time weighted average, over the entire mining career, of the percentage time in each job that shotfiring was done; secondly, the maximal percentage time shotfiring was done on all jobs; and thirdly, the total years of exposure to

Table 2 Comparison of years worked in mines that use water from various sources for dust control sprays

Water sources	Cases (n=85)		Referents (n=101) [†]		p Value
	Mean	SD	Mean	SD	
Holding tanks	9.8	13.1	5.2	9.4	0.0072
Recycled source	3.8	9.1	4.3	9.7	0.6920
Municipal supply	2.4	7.2	2.5	7.9	0.9778
Pond	8.4	10.5	9.4	11.7	0.5428
Running water	3.7	7.8	4.7	10.1	0.4188

[†]n=96 for recycled source.

shotfiring over all jobs during the miner's career, calculated as the sum over all jobs (percentage of time shotfiring was done in a mining job multiplied by the duration in that job). Finally, the years exposed to shotfiring was calculated as a proportion of the total years of mining exposure.

Various mining practices, such as handloading, longwall mining, continuous mining, roof bolting, and use of diesel equipment in underground mines were also queried among the respondents. Exposure variables for each of these practices were constructed in the same way as already described for exposure to shotfiring.

Certain mine characteristics were recorded, including the height of the seam, the average number of miners who worked underground in the mine, whether there was natural water in the mine (dry, standing, or running water), and finally, what was the source of water used for dust control sprays, categorised as surface ponds, running streams, municipal water systems, recycled water, or water from a holding tank at the mine (table 2). Comparisons between cases and referents were done for the total years worked in mines that used each source of water, and the frequencies of having worked at least 5, 10, or 20 years in a mine with a certain water source for dust control.

Cases and referents were also compared for demographic variables, spirometry indices, smoking status and pack-years, family and childhood medical history of allergy and respiratory illnesses, exposures from non-mining jobs or activities not related to work, and childhood exposure to smoke from cigarettes and domestic heating fuels. The variable for childhood passive smoking was determined by the number of family members who had smoked in the house. Exposure to domestic fuel smoke was assessed based on the reporting of visible smoke in the house while wood or coal was used for heating.

Multiple logistic and linear regression analyses

Stepwise multiple logistic regression and linear regression analyses were used to further evaluate the association of many variables of potential risk factors with clinically important decline in FEV₁. The outcome variable of case (yes=1, no=0) or FEV₁ slope was modelled with logistic or linear regression; the candidate independent variables examined were the same in both modelling procedures. Among the candidate risk factors, the selection of variables to be examined in the multiple regression models,

and the measurement expressions for these variables (either as continuous or dichotomous variable), were determined from the results of univariate group comparisons. Variables with either a trend or significant differences between cases and referents were chosen as candidates, and the most significant and simplest form of measurement was used in the model. Smoking status, respiratory protection, shotfiring, roof bolting, and indoor air pollution were entered into the model as dichotomous dummy variables. Respiratory protection was present if a miner had ever worn a respirator in any job when appropriate (yes=0, no=1). Roof bolting was present if a miner had ever done roof bolting (yes=1, no=0). Shotfiring exposure was present when, for any coal mine job, the maximal percentage time of exposure to shotfiring was $\geq 75\%$ (yes=1, no=0). Childhood passive smoking was present if two or more family members smoked in the house (yes=1, no=0). Childhood domestic fuel smoke was present if indoor exposure to fuel smoke was reported (yes=1, no=0). Age midway between surveys, weight gain slope (lb/year); and body mass index (kg/m²), duration of mining work, pack-years of smoking (both initial and final mine health surveys); total years worked in jobs with water from holding tanks for dust control; and follow up interval were entered into the model as continuous variables. Also examined in the process of modelling were variables for years of exposure to longwall mining activity, and for geographical mining regions. A dichotomous variable (yes=1, no=0) represented exposure to any of several regions that had been previously associated with an excess of case, compared with referent, miners.⁷ The correlation between various exposure variables was examined with Pearson's correlation analysis. A p value of 0.2 was used as a threshold for adding and removing variables on successive steps to the model. Maximal likelihood estimates of the logistic coefficients were obtained with the SAS statistical software package (SAS Institute, Cary, NC). Odds ratios (ORs) and 95% confidence intervals (95% CIs) were also calculated.

Results

GROUP COMPARISONS

Demographic and spirometry variables

Table 1 shows the demographic and spirometry variables at the initial and final mine surveys for miners who completed the new follow up questionnaire, as well as for those who were lost to follow up or declined to participate. Participants (n=264) and non-participants (n=370) were similar for age, height, pack-years of smoking, duration in underground face work, and spirometry indices at both initial and final surveys. In the referent group, the non-participants were heavier than the participants at both the initial and final surveys.

Among the 264 participating miners, at the final survey, cases had gained on average 5.9 lbs more weight (table 1) and had 1.4 more years of underground face work than referents (fig 1). Cases and referents were similar for pack-years of smoking at the final survey, however, at the

Figure 1 Duration of mining work at initial and final surveys among 121 case miners and 143 referent miners.

Figure 2 Use of any type of respiratory protection at work among 113 case miners and 138 referent miners. (A) Mean and maximal percentage of time protection was used on any job. (B) Total years of respirator use. p Value for cases v referents by Mantel-Haenszel χ^2 test.

initial survey cases had smoked slightly more than the referents. No differences between cases and referents were noted for age, height, initial FEV₁, and smoking. As expected, the annual rates of change in FEV₁, forced vital capacity (FVC), and FEV₁/FVC ratio were much greater for cases than referents.

Duration of mining

Duration at the face, underground, and in mining at the first survey was slightly greater among cases than referents. The differences persisted into the final survey, but were proportionately smaller (fig 1).

Further information about duration of mining work was provided by the follow up questionnaire. The average number of hours

worked each week, the amount of time away from the mines, and the proportion of time on lay offs were not significantly different between cases and referents. At the time of the follow up interview, 28% of the case miners and 37% of the referent miners were still working ($p=0.169$); but only 13% of the case miners and 24% of the referent miners were in coal mining jobs ($p=0.031$).

Respiratory protection

Of 138 referents who provided information on respirator use, 90 (65.2%) reported ever wearing a respirator; this proportion was only 53/113 (46.9%) among the cases ($p=0.005$). In general, the various measurements for respiratory protection—such as mean or maximal percentage of time wearing a respirator (fig 2 A) or the number of years of respirator wear (fig 2 B)—were significantly greater in referents than the cases. In particular, for jobs involving longwall mining, referents reported nearly double the proportion of miners who used respiratory protection (22.8%) than did the cases (13.1%, $p=0.077$).

Mining activities and working conditions

Four variables were used to assess exposure to underground mining activities and working conditions for each miner. These exposure variables were the maximal percentage of time, the mean percentage of time, the years in a particular mining job or working condition, and the proportion of exposed years to total years of mining. In general, for all four variables, cases had on average more exposure to underground face work, shotfiring, roof bolting, and hand loading. By contrast, exposure to longwall mining was greater among the referents. Continuous mining was a major mining activity for both cases and referents; the mean percentage of time with continuous mining exposure was 36% for cases and 38% for referents. The use of diesel equipment in underground mines and work in maintenance, as a mechanic, or electrician were also similar between cases and referents (data not shown). Table 3 shows the joint distribution of the exposure variables for shotfiring and for roof bolting. For both these variables, cases had greater exposure than referents, and these findings were significant by the Mantel-Haenszel χ^2 test (data not shown).

Mine characteristics

Mine seam height—We defined a seam height ≤ 50 inches as a low seam mine, and compared the total years worked in low seam mines between the two groups. Cases and referents averaged 7.2 and 5.4 years ($p=0.21$), respectively.

Mine size—Mine size was defined by the average number of miners working per day in the mine. We classified a mine with <50 underground employees as a small mine. The cases worked in small mines on average 2.5 years, whereas referents worked 1.7 years ($p=0.24$). Of the cases, 29.4% reported they had ever worked in a small mine, whereas only 19.0% of the referents reported this ($p=0.069$). Years of

Table 3 Joint distribution of exposure to explosive blasting (shotfiring)* and roof bolting work† among case and referent miners (n (%))

	Neither exposure	Explosive blasting only	Roof bolting only	Both blasting and roof bolting
Cases (n=108)	39 (33)	4 (80)	54 (53)	11 (61)
Referents (n=134)	79 (67)	1 (20)	47 (47)	7 (39)
Total	118 (100)	5 (100)	101 (100)	18 (100)

*Any mining job with maximal time of exposure to shotfiring $\geq 75\%$.

†Any exposure.

Table 4 Joint distribution of childhood exposure to passive tobacco smoking* and domestic fuel smoke† among case and referent miners (n (%))

	Neither exposure	Tobacco smoke only	Fuel smoke only	Both tobacco and fuel smoke
Cases (n=119)	56 (40)	13 (62)	37 (49)	13 (57)
Referents (n=142)	85 (60)	8 (38)	39 (51)	10 (43)
Total	141 (100)	21 (100)	76 (100)	23 (100)

*Two or more smoking household members.

†Any domestic exposure to wood or coal smoke.

work in small mines was correlated with work in low seam coal ($R=0.31$, $p=0.0001$).

Water in the mine—Comparisons between cases and referents were made for each source of water used for dust control in the mine. No significant differences were noted for recycled or municipal supplied water, running water, or water from a pond. However, a highly significant difference was evident with water from holding tanks for dust control sprays in the mine. Cases worked on average a total of 9.8 years in mines with water from holding tanks for dust control, compared with 5.2 years for referents ($p=0.0072$). Among those working >0 – <10 , ≥ 10 – <20 , or ≥ 20 years in mines that used water from holding tanks, there were significantly more cases than controls for each increasing level of exposure to tank water. When natural water in the mines was evaluated, the total years worked in mines with natural standing water, running water, or in a dry mine were very similar in both groups. Years of work in mines with holding tanks was correlated with years worked in low seam coal mines: $R=0.28$, $p=0.0001$, and also with duration of underground work: $R=0.25$, $p=0.0005$.

Medical history and domestic exposures

We examined differences between cases and referents in family history (allergies and respiratory illnesses), childhood domestic living conditions, and personal history of allergy and

respiratory diseases. Comparisons of environmental exposures outside of work were also made.

More cases than controls reported contracting pneumonia before the age of 16 (14.3% *v* 6.2%; $p=0.061$).

As the number of family members who had smoked in the house during the miner's childhood increased from 0–1, 2, 3, and 4, the proportion of cases was 44%, 42%, 51%, 60%, and 100%, respectively. Childhood passive smoking, defined as the presence of two or more smokers in the house, was reported by 26% (31/119) of cases versus 17.6% (25/142) of the referents ($p=0.133$). Indoor exposure to fuel smoke (when either wood or coal was used to heat the house) was reported by 42.0% of the cases, compared with 34.5% of referents ($p=0.264$).

Indoor air pollution, a combined variable defined as childhood exposure to either passive smoking (two or more family members) or indoor fuel smoke, was reported in 52.9% of cases, compared with 40.1% of referents ($p=0.052$). The joint distribution for exposures to passive smoking and indoor fuel smoke is shown in table 4.

LOGISTIC REGRESSION ANALYSIS

Two separate models are presented below. Model 1 did not include the variable for use of water from holding tanks for dust control sprays. Model 2 incorporates a term for this source of mine water, but includes only 179 subjects, due to missing information on this variable.

Model 1

Sufficient information was available to include 236 subjects in this logistic regression model (variables are shown in table 5). Model 1 showed that several variables related to mining, including duration in underground mining work, not wearing respiratory protection, and mining activity of roof bolting, were independently related to the risk of a clinically important decline of FEV₁. Interestingly, when duration of underground mining work was used as a measure of exposure to dust in the univariate comparisons, the difference between cases and referents was not significant. However, in model 1, when adjustment was made for other candidate risk factors, including use of respirator protection, roof bolting work, exposure to shotfiring, and mining region, the effect of years of underground mining was statistically apparent. Other variables associated with decline in FEV₁ were personal smoking, childhood passive tobacco smoking, body mass index at the final survey, and weight gain slope. After controlling for these covariables, the OR (95% CI) for non-use of a respirator was 2.2 (1.2 to 3.9). Thus, compared with miners who had worn a respirator at least some of the time during their career, miners who never wore respirators had 2.2 times the risk of being classified as a case. The OR (95% CI) for exposure to shotfiring (maximal percentage time shotfiring $\geq 75\%$ in any job) was 2.2 (0.8 to 6.1). The

Table 5 Determinants associated with clinically important decline in FEV₁ in two logistic regression models

Independent variable	Odds ratio (95% CI) / p value	
	Model 1 n=236	Model 2 n=179
Respirator use (yes=0, no=1)	2.163 (1.191 to 3.930) $p=0.0113$	2.458 (1.216 to 4.969) $p=0.0123$
Roof bolting (yes=1, no=0)	2.087 (1.148 to 3.794) $p=0.0158$	1.627 (0.824 to 3.214) $p=0.1609$
Shotfiring exposure (yes=1, no=0)	2.195 (0.791 to 6.090) $p=0.1312$	2.343 (0.740 to 7.421) $p=0.1477$
Coal face work at initial survey (y)		1.045 (0.998 to 1.094) $p=0.0590$
Use of water from holding tank (y)		1.038 (1.006 to 1.071) $p=0.0214$
Underground mining at final survey (y)	1.032 (1.000 to 1.065) $p=0.0521$	
Regional effect* (yes=1, no=0)	1.783 (0.971 to 3.276) $p=0.0623$	
Smoking at initial survey (pack-years)	1.023 (0.999 to 1.046) $p=0.0569$	1.027 (0.999 to 1.054) $p=0.0556$
BMI at final survey (kg/m ²)	1.091 (1.000 to 1.190) $p=0.0509$	1.102 (1.002 to 1.212) $p=0.0448$
Weight slope (lb/y)	1.397 (1.096 to 1.782) $p=0.0070$	1.360 (1.029 to 1.796) $p=0.0304$
Passive smoking† (yes=1, no=0)	2.147 (0.977 to 4.717) $p=0.0572$	

*Work in a region in which excess functional declines had previously been shown.⁷

†Childhood domestic exposure to passive smoking.

Table 6 Multiple linear regression models for longitudinal decline of FEV₁ (l/y), corresponding to the logistic regression models in table 5

Independent variable	Partial coefficient (SEM) p value	
	Model 1 n=236	Model 2 n=179
R ²	0.1983	0.1911
Constant	0.0155 (0.0102) p=0.1301	0.0142 (0.1114) p=0.2041
Respirator use (yes=0, no=1)	-0.0131 (0.0062) p=0.0355	-0.0170 (0.0075) p=0.0246
Roof bolting (yes=1, no=0)	-0.0214 (0.0062) p=0.0006	-0.0228 (0.0073) p=0.0021
Underground mining at final (y)	-0.0007 (0.0003) p=0.0272	-0.0010 (0.0004) p=0.0117
Mining region* (yes=1, no=0)	-0.0123 (0.0064) p=0.0567	
Smoking at initial survey (pack-years)	-0.0007 (0.0002) p=0.0061	-0.0007 (0.0003) p=0.0118
Weight slope (lb/y)	-0.0093 (0.0023) p=0.0001	-0.0102 (0.0027) p=0.0002
Passive smoking† (yes=1, no=0)	-0.0121 (0.0082) p=0.1408	
Fuel smoke exposure‡ (yes=1, no=0)	-0.0097 (0.0064) p=0.1307	

*Work in a region in which excess functional declines had previously been shown.⁷

†Childhood domestic exposure to passive smoking.

‡Childhood domestic exposure to smoke from coal or wood fuels.

OR (95% CI) for childhood domestic exposures to tobacco smoke was 2.1 (1.0 to 4.7).

Model 2

In this analysis, we examined the effects of use of water from holding tanks for dust control sprays (n=179). When years worked in a mine with water from holding tanks was included as a covariable, the model results showed a significant association between use of water from holding tanks and being a case. Each additional year of working in a mine that used water from holding tanks for dust control purposes was associated with a 4% increase in the odds of a clinically important decline in FEV₁. Variables for underground mining, mining regional effects, and childhood passive tobacco smoking did not remain in this model, although the other independent variables entering the model were similar to model 1 (table 5).

LINEAR REGRESSION ANALYSIS

A linear model for the outcome variable of FEV₁ slope was also investigated, with the same candidate independent variables as for the logistic models. The findings in general were similar to the logistic models (table 6). However, in the linear model 2, an effect of underground mining was apparent with linear regression, but not in the logistic model. By contrast, the effects of water from holding tanks were found in the logistic model, but not in the linear model. An interaction term between mine region and holding tank water did not enter the models.

Discussion

The association between occupational exposure to dust and decline in lung function has been noted in many studies. However, in virtually all longitudinal studies of lung function, only a small part of the observed variability in decline in lung function is explained by variables such as tobacco smoking, age, and occupational exposure to dusts. We evaluated other potential risk factors for decline in lung

function, attempting to define hypotheses for future research and preventive strategies.

The results from this study indicate that occupational factors including coal mine exposure to dusts, use of respiratory protection, exposure to shotfiring, and to aerosols of water from holding tanks may have implications for clinically important decline in lung function. There was a tendency for the miners with high rates of decline in FEV₁ to have worked more in small mines (p=0.069), although at least 564 subjects (v the 264 in this study) would have been required to have >80% power to detect such a difference. At the time of the follow up interview, miners with excessive decline in FEV₁ were less likely to be employed, especially in mining jobs, a finding consistent with the adverse socioeconomic consequences of reduced lung function, and suggesting a potential mechanism for the healthy worker effect.⁸

Our results also suggest that loss in ventilatory function may be associated with several personal risk factors—such as smoking, childhood pneumonia, childhood domestic exposures to passive tobacco smoke, and possibly smoke due to wood and coal fuels. Increasing body mass and weight gain were also associated with cases. However, among the referents miners, non-participants in the study weighed more than participants, and thus the association of cases with body mass index may have resulted, at least in part, from a participation bias. Also, the design of this study does not permit assessment of whether the decline in lung function could be a cause or a result of the weight gain.

It is not entirely possible to exclude an effect of recall bias in these findings. However, the initial case selection was based upon testing done many years before administration of the questionnaire, and neither the interviewers nor the participants were aware of the case status during the interviews, so any potential recall effect should have been minimised. Also, when all responses from family members (9%) were excluded from the models, the results were unchanged from those shown in tables 5 and 6 (data not shown).

USE OF RESPIRATORY PROTECTION

Standard industrial hygiene practice suggests that control of exposures at the source is the preferred approach of hazard control. However, when used as part of a comprehensive programme, respiratory protection can reduce worker exposures.⁹ In this study, the use of these devices was found to be significantly greater in the referent miners than the cases, suggesting an important protective effect.

Most miners in this study reported some use of respiratory protection. Use patterns varied considerably and only a few miners reported that they used respirators on average more than 10% of the time. However, there is evidence to suggest that miners keep their use of respirators for more dusty work, and thus intermittent use may still result in effective reductions in exposure.¹⁰ As use of respirators was not generally ascertained in previous studies, it is plausible that some of the previously unexplained

variation in decline in lung function in workers exposed to dust is related to this. For example, longwall mining is a highly mechanised, labour efficient method of coal mining that is used in many modern underground coal mines, but which may be associated with high concentrations of respirable dust.¹¹ It was therefore unexpected that the mean percentage of time exposed to longwall mining was significantly less for cases than for referents in this study (data not shown). Interestingly, for jobs in longwall mining, referent miners reported use of respiratory protection about twice as much as the cases, suggesting that the apparent reduced risk of longwall mining was at least in part related to greater use of respiratory protection. Use of respiratory protection may also reflect availability of protective devices as well as policies of the employers towards hazard control. These issues were not explored in this study.

TOXIC FUMES FROM SHOTFIRING IN COAL MINES

Detonation of explosives in coal mines produces several potentially hazardous exposures: (a) rock and coal dust, (b) unreacted particles of explosive, (c) droplets of nitric and nitrous acids, and (d) gases including carbon dioxide, ammonia, carbon monoxide, hydrogen sulphide, and oxides of nitrogen. The main acute toxicities relate to carbon monoxide and oxides of nitrogen. Kennedy, in 1972, studied the health effects of fumes generated from shotfiring in 100 underground coal miners over a 10 year period. The findings suggested that both acute and chronic illness may result from excessive exposure to fumes from shotfiring. Short, heavy exposures to fumes may result in acute chest illness from which there may be full recovery. However, lower exposures to fumes over months or years was associated with the development of an emphysema-like condition. Many of the miners who developed acute pulmonary oedema or severe acute chest illnesses also had prolonged exposure to fumes and later developed emphysema.¹²

By contrast, Robertson *et al*, in 1984, studied 44 carefully matched pairs of miners with either high and low exposure to oxides of nitrogen, from a cohort of 560 British coal miners. They were unable to detect long term effects on respiratory symptoms or level of FEV₁ or rate of decline for the then current exposures to nitrogen oxide. However, the exposures to oxides of nitrogen in the collieries studied were in general well below accepted threshold values, although occasional peaks did exceed short term limits.¹³

Gunnar, in 1993, reviewed the controlled exposure studies on humans, and concluded that NO₂ clearly causes bronchoconstriction in normal subjects at about 4.5 ppm, and probably also at concentrations of about 2–2.5 ppm, but <1 ppm no significant effects on lung function can be detected.¹⁴ In an investigation by Nicholas and Wall, in 1971, on the pollution in coal mine headings following shotfiring, the highest concentration of NO₂ was 70 ppm; a peak of 30 ppm was measured for a time and

location where men were likely to have been working.¹⁵

In our study, the results from both group comparisons and the logistic regression analysis suggested that extensive exposure to shotfiring was related to clinically important longitudinal decline in FEV₁.

WATER SOURCES IN THE MINE

The use of water in coal mines is high. Water sprays and wet drilling are routinely used to suppress dust. Comparisons between cases and referents were made for each source of water used for dust control in the mine; a highly significant difference was evident for the use of water from holding tanks to control dust by spraying in the mine. The logistic model, but not the linear model, confirmed the univariate finding. Water in holding tanks can be a medium in which the concentration of common environmental microorganisms may be augmented. A plausible explanation for the association found is that when the water is aerosolised, micro-organisms and their products can be disseminated to the lung. To our knowledge, this association has not previously been noted in mining. However, exposure to aerosols of contaminated water based fluids has been associated with respiratory disease in industrial and other working environments. Both acute illnesses and chronic respiratory disease have been described.^{16–18}

CHILDHOOD RESPIRATORY ILLNESS

Associations between childhood lower respiratory illness and adult chronic obstructive pulmonary disease have been consistently reported.^{19–22} In our study, miners were asked whether they had pneumonia before the age of 16. Among miners who had a high rate of decline in FEV₁, childhood pneumonia was reported by 14.3% compared with 6.2% of the referents ($p=0.037$).

INDOOR AIR POLLUTION

Our data indicate an association between childhood exposures to passive smoking and possibly to coal or wood smoke, and a rapid decline in FEV₁ in later life. Also, the effect of passive smoking was more apparent when the smoking relative was either the mother or the sister, compared with the father or brother, perhaps related to the amount of time spent in the home.

Numerous other studies have documented adverse effects of indoor air pollution on respiratory health. Passive smoking during infancy and childhood has been associated with acute respiratory illness, chronic respiratory symptoms, and reduced pulmonary function. Burchfiel *et al* reported a relation between passive smoking and respiratory conditions and reduced pulmonary function in a study of 3482 children and adolescents in Tecumseh, Michigan.²³ Masi *et al* studied 293 non-smoking young men and women, 15–35 years of age, and found that maternal smoking habits and exposure to second hand smoke during childhood were the exposures most closely related to reductions in forced expiratory flow

between 25% and 75% of the maximum (FEF₂₅₋₇₅).²⁴ More recently, Xu and Li reported on exposure-response relations between passive smoking and pulmonary function in adulthood in a random sample of 1033 adults aged 40–69 years from a residential area in Beijing, China. A significant and dose-dependent relation was found in adults between passive exposure to tobacco smoke either at home or at work and reductions in FEV₁ (102 ml) and FVC (151 ml).²⁵ Tager *et al* reported a 7 year prospective study of the effects of maternal smoking on pulmonary function in 1156 children. After correction for confounders including cigarette smoking in the child or adolescent, maternal smoking was associated with a significant reduction in the expected growth in FEV₁. The results from this study suggested that passive exposure to maternal cigarette smoke may have important effects on the development of pulmonary function in children.²⁶

Conclusions

This study investigated several potential risk factors for longitudinal decline in lung function, with questionnaire responses from a group of 264 underground coal miners. Results confirmed the previously noted associations between excess decline in FEV₁ in adulthood and exposure to dust, tobacco smoking, childhood pneumonia, and childhood exposures to smoke. The importance of considering these factors in future studies of respiratory health is reinforced. We also identified several work practices that were associated with clinically important decline in lung function, including roof bolting, explosive blasting, lack of use of respiratory protection, and dust control sprays that used water that had been stored in holding tanks. Interestingly, when duration of mining work was used as a measure of exposure to dust, the difference between cases and referents did not reach a significant level in group comparisons (fig 1). However, with a multivariate analysis, and adjusting for other covariables, including mining region, use of respirator protection, roof bolting, shotfiring, and the potentially contaminated water from holding tanks, the effect of years of underground face work and years of underground mining were significant (logistic and linear models 1 and 2). Although the importance of the additional risk factors investigated in this study cannot be considered to be proved, they represent biologically plausible explanations for the findings, and are consistent with current knowledge. Further research is needed to confirm these results, and to determine whether the findings of this study may be useful in developing new approaches to the prevention of chronic respiratory disease among workers exposed to dust.

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