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Prevalence of Pneumoconiosis and Its Relationship to Dust Exposure in a Cohort of U.S. Bituminous Coal Miners and Ex-Miners

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Information on radiographic evidence of coal workers' pneumoconiosis (CWP) is presented for a group of 3,194 underground bituminous coal miners and ex-miners examined between 1985 and 1988. Prevalence of CWP was related to estimated cumulative dust exposure, age, and rank of coal. On the basis of these data, miners of medium to low rank coal, who work for 40 years at the current federal dust limit of 2 mg/m^3, are predicted to have a 1.4% risk of having progressive massive fibrosis on retirement. Higher prevalences are predicted for less severe categories of CWP. Miners in high rank coal areas appear to be at greater risk than those mining medium and low rank coals. Ex-miners who said that they left mining for health-related reasons had higher levels of abnormality compared to current miners.

Key words: coal workers' pneumoconiosis, CWP, risk, radiographic abnormality, progressive massive fibrosis, coal miners, retired workers, ILO classification

INTRODUCTION

Among the requirements of the 1969 Federal Coal Mine Health and Safety Act (FCMHSA) [Coal Mine Health and Safety Act, 1969] was the stipulation that research into the health of coal miners be undertaken. As a result, a large epidemiological study of U.S. coal miners was begun by the U.S. Public Health Service soon after passage of the Act. The results presented here comprise the latest information from this study on prevalence of coal workers' pneumoconiosis (CWP) and its relationship with dust exposure.

The epidemiological study, denoted the National Study of Coal Workers' Pneumoconiosis (NSCWP), was begun in 1970 [Attfield and Castellan, 1992]. Initially, 31 underground mines around the country were visited by a mobile examination trailer staffed by a medical team. Radiological data, information on ventilatory function and respiratory symptoms, and data on work and smoking history were obtained on over 9,000 active miners. Completed in 1971, this first round of the study was followed by similar second and third rounds of medical surveys of active miners at

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essentially the same mines at roughly 5-year intervals. The data presented here are drawn from the most recent (1985–1988) round of surveys, i.e., Round 4, a follow-up study of selected Round 1 and Round 2 participants.

Many of the miners in the studied cohort had started work in coal mining around 1970. Much, if not all, of their mining tenure therefore coincides with the period when dust levels were mandated to be 3 mg/m^3 (1970–1972) and 2 mg/m^3 (1972 onwards) [Coal Mine Health and Safety Act, 1969]. These levels compare to dust concentrations of 6 mg/m^3 or more for face workers recorded before 1970 [Jacobson, 1971] and applicable to a previous exposure-response analysis of CWP [Attfield and Morring, 1992b]. The results given in this report therefore not only provide further information on exposure-response, but also supply information pertinent to miners working in current coal mining conditions.

MATERIALS AND METHODS

Cohort Derivation

Participants in Round 1 or 2 of the study who had been working in bituminous coal mines and were alive according to Internal Revenue Service records and aged 58 years or less in 1985 were identified. The age limit was imposed in order to confine the planned medical investigation to those within the normal working age range. The cohort consisted of 7,281 miners and ex-miners, about equally divided between those first examined at Round 1 and those first examined at Round 2.

Not all the 7,281 were finally selected for study. Those who had moved to locations outside of the principal coal mining areas, those in thinly populated areas, and those deemed too far (about 30 miles) from the planned locations of the mobile examination unit were excluded. There remained 5,693 miners and ex-miners who were finally targeted for examination in 26 preselected locations. These consisted of three active mine sites and 23 non-mine sites referred to as "community surveys" henceforth (more mine surveys were not possible because the study mines had been closed down or were temporarily inactive during the medical examination phase of this round).

Surveys

The targeted group was divided into clusters of about 150–400 people, and a visit made to each location to seek a convenient site (e.g., health clinics, shopping malls, and union halls) for the mobile examination unit. Individuals were contacted by a locally employed telephonist, and examinations scheduled at their convenience. As considerable difficulty was experienced in obtaining telephone numbers for some, letters were sent to their homes. Personal visits were made to the homes of nonresponders to arrange an appointment for examination.

About 3–4 weeks after the telephonist had started making calls, the mobile examination unit was moved to the chosen site and the survey proper began. While a team of technicians obtained the medical data, others continued to locate individuals and schedule examinations and to reschedule examinations for those who failed to keep their appointments.

Size of Study Group and Bias

OF 5,693 targeted, 3,280 miners and ex-miners participated in the examinations (see Table I for the complete breakdown by category). In order to detect any bias

TABLE I. Derivation of Final Group of Coal Miners

Round 1 and 2 participants, age ≤58 in 1985		7,281
Excluded from invitation based on locality: too few or too distant		1,588
Targeted group		5,693
Non-participants		
Deaths	136	
Moved away	417	
Not located	390	
Refused/no show	1,128	
Other	342	
Total		2,413
Examined in 3 mine and 23 non-mine sites		3,280
Excluded due to unreadable x-rays or missing exposure data		86
Number available for analysis		3,194

caused by the selection procedures for the targeted individuals, the initial data from Rounds 1 and 2 for the 7,281 people in the follow-up cohort were combined and tabulated by whether or not they had been targeted for examination. A similar analysis compared differences between participants and those of the targeted group who were not medically examined. This latter analysis excludes the 136 individuals who died before they were examined.

Medical Examination

The examination consisted of three main parts: a posterior-anterior chest radiograph, spirometry, and a questionnaire on respiratory symptoms, smoking habits, and work history. The coal mining jobs were classified according to the coding system used by the Mine Safety and Health Administration (MSHA) in order to facilitate amalgamation with MSHA dust concentration data for the development of estimated occupational dust exposures. Additional questions were asked of the miners concerning age, race, and other dust exposures (i.e., work in quarries, in foundries, in cotton, hemp, and flax mills, in potteries, and with asbestos).

Ex-miners were asked about their reasons for leaving work in coal mining, and were placed into one of two groups based on their replies: health-related ex-miner (left coal mining because of sickness or injury), and work-related ex-miner (left coal mining to take another job, or laid off).

Coal Rank

The study participants were divided into three broad groups for analysis by coal rank, a mineralogic measure of the degree to which coal has been metamorphosed by heat and pressure. Previous studies have shown coal rank to be a risk factor for development of CWP [Walton et al., 1977; Attfield and Castellan, 1992]. Participants living in central Pennsylvania and southeastern West Virginia were put into the high rank coal group, while those residing in western Kentucky, Illinois, Colorado, and Utah were placed in the low rank coal group. All others comprised a medium rank group. These geographic groupings fit with general trends in coal rank across the country. (Separate categorization of the western miners was not possible because of small numbers.)

X-ray Readings

Independent classifications of all single films from Round 4 were undertaken by three (National Institute for Occupational Safety and Health (NIOSH)-certified B readers using the ILO 1980 system [International Labour Office, 1980]. Since wide variability in classifications by B readers has been reported [Attfield et al., 1986], a special reader selection strategy was adopted with the intent to minimize interreader disagreement while providing readings representative of B readers in general (i.e., avoiding extremes of interpretation). Readings from the Coal Workers' X-ray Surveillance Program (CWXSP) [Attfield and Althouse, 1992] made over the period 1981–1985 were employed to rank the 30 participating B readers. These readers had each classified hundreds of x-rays of current miners, supplied to them more or less randomly with regard to tenure and region. The percentage of x-rays reported to have category 1 or greater was tabulated for each reader. The readers were then ranked by this percentage, and three readers selected from the center of the range. Part way through Round 4, one of the selected readers retired and was replaced by another, who was selected using the same procedure.

A summary profusion category of small opacities for each study participant was obtained by taking the median category when three readings were available. To avoid loss of data, for those cases where only two readings were available, through one reader saying the film was unreadable, the higher of the two available profusion categories was taken as the summary determination (n = 162). Films with only one reading were omitted from analysis (n = 80). Median determinations of large opacities (progressive massive fibrosis [PMF]) were derived similarly.

In this report, the term CWP refers generically to radiologic evidence of small opacities and/or large opacities detected using the ILO Classification scheme. CWP 1+ will refer to any x-ray showing major category 1, 2, or 3 small and/or large opacities. CWP 2+ will refer to major category 2 or 3, and/or large opacities. PMF denotes any category of large opacities.

Dust Exposures

Dust exposure estimates for each person were calculated by summing the products of time worked in each job from the Round 4 work histories with dust concentration data from the exposure matrix derived by Seixas et al. [1991]. Estimates of dust levels prior to the systematic collection of environmental information mandated by the FCMHSA in 1969 were derived by extrapolation of the 1970–1972 information. This used the factor of 2.3 derived by Attfield and Morring [1992a] from Bureau of Mines data collected in 1968–1969. The resulting exposure estimates are expressed in mg-yr/m^3, and represent the cumulative exposure experienced from starting work until the date of the Round 4 medical examination.

Statistical Analysis

Relationships between CWP prevalence and estimated cumulative dust exposure were determined using logistic modeling of presence/absence of CWP 1+, of CWP 2+, and of PMF against dust exposure allowing for age, i.e.,

$$\ln(p/(1-p)) = a_0 + a_1 A + a_2 E$$

where p represents the prevalence of CWP, A is age, and E is exposure. This form of equation follows closely that used in an earlier analysis of data from Round 1 of the study [Attfield and Morring, 1992b].

Differences in prevalence between coal rank regions were explored by fitting separate exposure terms by region, i.e.,

$$\ln(p/(1-p)) = a_0 + a_1 A + a_2 E_H + a_3 E_M + a_4 E_L$$

where E_H, E_M, E_L represent exposures for each coal rank region.

Differences among the three mining status groups (current miner, health-related ex-miner, and work-related ex-miner) were assessed by adding separate constant terms to the above model. (For simplicity, the low and medium rank groups were combined for this analysis, as the coal analysis had revealed no difference between them.)

Finally, a comparison of the effects of dust exposure experienced before and after 1970 was made by dividing the total exposure into its two respective components and substituting those estimates into the model in place of the single estimate of overall exposure. (Separate pairs of coefficients were created for high rank group and for the low and medium rank groups combined.) To test the hypothesis that the effect of dust exposure on prevalence did not depend on the time period when the exposure occurred, the difference between the coefficients was tested against zero using a standard error derived from the respective variances and covariance of the coefficients.

RESULTS

General Information

The distribution by state of the total follow-up group of 7,281 miners and ex-miners and those finally targeted for examination is shown in Figure 1. This indicates that roughly equal proportions of miners were targeted from the major coal producing states (Kentucky, Pennsylvania, Virginia, West Virginia). The proportion of targeted miners in Illinois was lower than for all other states as the miners lived in small towns scattered across the state; resources did not permit visits to all of the areas. Conversely, the miners in three of the remaining states (Alabama, Tennessee, Utah) tended to cluster together, resulting in the targeted percentages being higher than for other states.

Based on replies given during examination, 53% of the group were current miners, while 33% were work-related ex-miners (mostly laid off because of the recession in coal mining). Health-related ex-miners made up the balance (14%).

The Round 1 and Round 2 segments of the cohort differed little from each other, having almost identical distribution by state. Those from Round 2 were slightly younger on average and had spent about 2 fewer years in mining than had their Round 1 colleagues. This was probably due to the recruitment of new miners brought about by the energy crisis around the time Round 2 was being undertaken.

Reasons for the non-participation of targeted individuals were: death (2%), refusal (9%), moved away (7%), could not be located (7%), given appointment(s) but

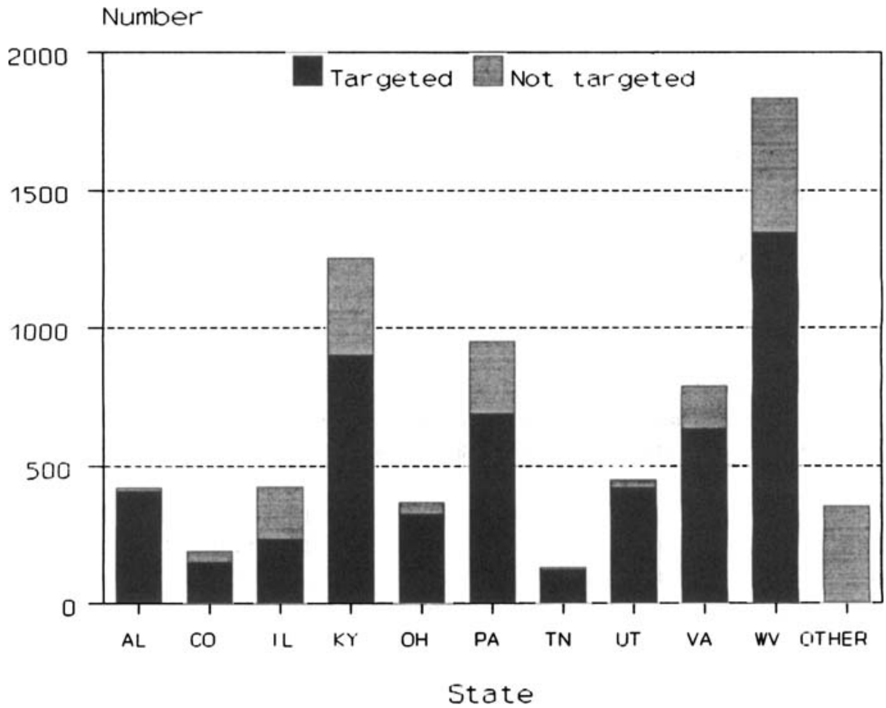

Fig. 1. Number of preliminary cohort miners targeted for medical examination by state of residence at Round 4.

did not show up and could not be rescheduled (11%), and miscellaneous reasons (5%) (Table I).

The dust exposures ranged from 0 to 211 mg-yr/m^3, with 75% lying between 13 and 41 mg-yr/m^3, the mean and SD being 34 and 32 mg-yr/m^3, respectively.

Bias

An exploration of selection bias (Table II) showed that there was essentially no difference with regard to age, years underground, and prevalence of CWP 1+ at Round 1 or 2 between the miners targeted for examination and those not targeted.

Statistics pertinent to participation bias among the 5,693 individuals targeted for examination are given in Table III. The data are broken down into those who did and did not attend for medical examination at Round 4. The two groups were very similar with regard to age, but non-participants had worked slightly longer underground. Despite this, the non-participants had a slightly lower prevalence of CWP 2+.

Prevalence of CWP

Radiographs for 80 individuals were said to be unreadable by two or more readers. In addition, estimated exposures could not be computed for six due to poor work history data. Accordingly, results on prevalence and exposure-response are based on the remaining 3,194 participants.

Similar overall prevalences of CWP 1+ were obtained by the three readers

TABLE II. Exploration of Selection Bias Among U.S. Coal Miners: Descriptive Statistics From Rounds 1 and 2 for the Complete Cohort, and for the Subsets Targeted and Not Targeted for Examination

		Targeted	
Variable	All	Yes	No
Number	7,281	5,693	1,588
Mean (SD) age (years)	31 (8)	32 (8)	31 (8)
Mean (SD) years underground	6 (7)	6 (7)	6 (7)
% CWP 1+	4	4	4
% CWP 2+	0.6	0.6	0.6

TABLE III. Exploration of Participation Bias Among U.S. Coal Miners: Descriptive Statistics From the Round 1 and 2 Data for the Targeted Group, Divided Into Participants and Non-Participants*

	All targeted	Participated at Round 4	
Variable	individuals	Yes	No
Number	5,557	3,280	2,277
Mean (SD) age (years)	31 (8)	32 (8)	31 (8)
Mean (SD) years underground	6 (7)	6 (7)	7 (8)
% CWP 1+	4	4	4
% CWP 2+	0.6	0.7	0.4

*Total number targeted excludes 136 individuals who died before they could be examined.

(7%, 7%, and 9%, respectively). This similarity persisted when the data were tabulated by deciles of estimated dust exposure (Fig. 2). CWP 1+ prevalence based on the median determinations (also shown on Fig. 2) was less than 5% for those individuals with less than 30 mg-yr/m^3 but rose to close to 30% among those with the highest exposures. CWP 2+ prevalence (median determinations) was less than 1% among individuals with less than 30 mg-yr/m^3 of dust exposure, but rose thereafter to close to 10%.

CWP Prevalence, Dust Exposure, and Coal Rank

Prevalence of CWP 1+ against dust exposure is shown for the three coal rank groups in Figure 3 (644 from the high coal rank region, and 1,779 and 555 from the medium and low rank regions, respectively). For all three groups, obvious trends of increasing prevalence with increasing exposure are seen, the steepest slope occurring in the high rank group. Logistic modeling on CWP 1+ allowing for age and dust exposure within region revealed that dust exposure and age were both related to prevalence (Table IV). Furthermore, an additional effect of dust exposure for high rank miners was seen. Identical modeling for CWP 2+ led to very similar findings (Table IV).

CWP Prevalence and Employment Status

Prevalence of CWP 1+ according to employment status at Round 4—current miner, ex-miner (job-related), or ex-miner (health-related)— is shown plotted against dust exposure in Figure 4. The prevalences among the 456 individuals who said they

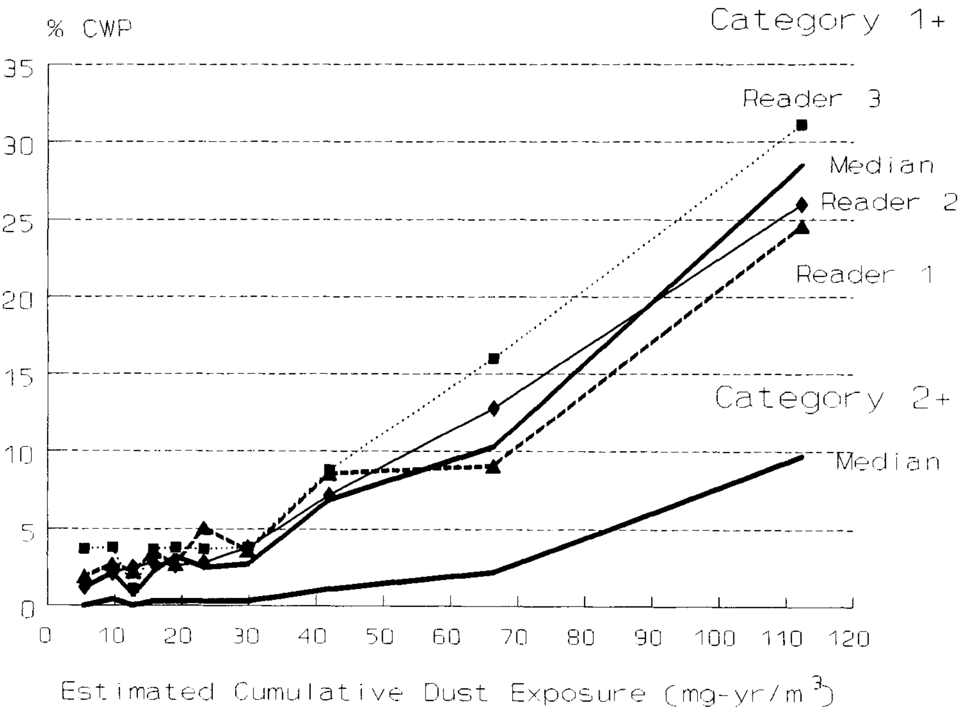

Fig. 2. Prevalences of CWP 1+ by reader and median, and prevalences of CWP 2+ by median, by deciles of estimated dust exposure.

left mining because of their health were generally greater than for the other two groups, especially for the group with the largest dust exposure. This impression was confirmed by logistic modeling after adding separate constant terms to the model for coal rank ($p < 0.05$), although the effect is not particularly strong.

Comparison of Effects of Dust Exposure Before and After 1970

Replacement of the overall exposure estimates in the logistic modeling by partitioned terms pertinent to exposure up to 1970 and exposure after that time showed that exposure during both time periods appeared to contribute to the development of CWP 1+ in the combined low and medium coal rank groups ($p<.0001$ for pre-1970 exposure and $p<.01$ for post-1969 exposure) in the complete cohort. Although the term for post-1970 exposure appeared greater (−.030 compared to −0.014), suggesting greater influence of the post-1970 exposure, this interpretation was not supported by the test of significance of the difference in the coefficients ($p>0.05$). The findings for the high rank group supported this conclusion.

PMF Results

Tabulation of the median PMF determinations from the prevalence reading revealed 28 cases, 17 of which were category A, 9 B, and 2 C.

Logistic modeling of presence/absence of PMF revealed that age and overall dust exposure were statistically significant predictors. Moreover, as with simple

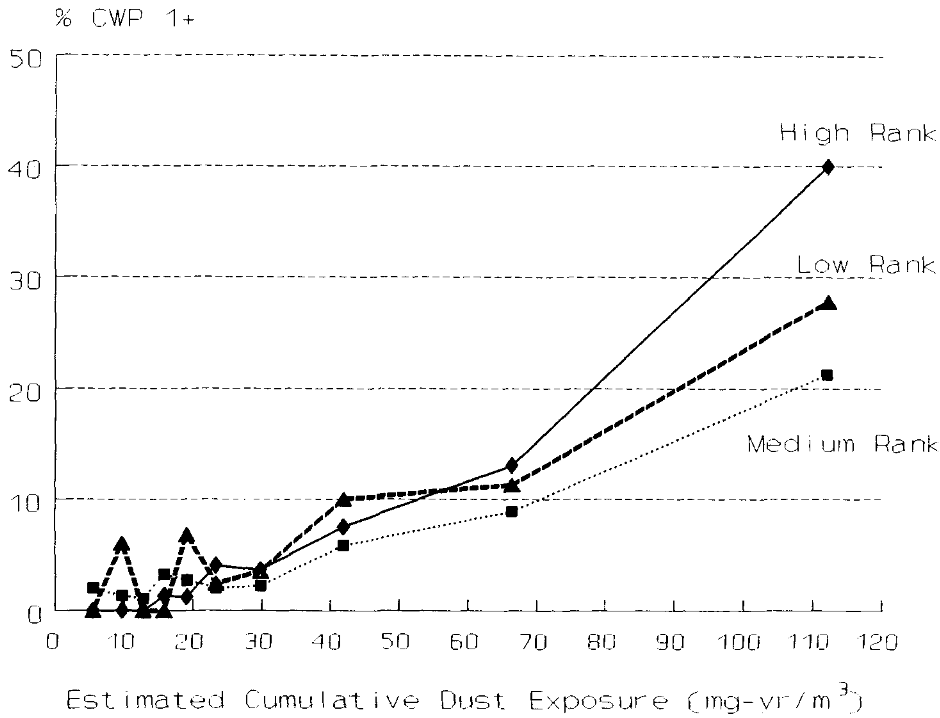

Fig. 3. Prevalences of CWP 1+ (median determinations) by deciles of estimated cumulative dust exposure and coal rank group.

TABLE IV. Coefficients and Related Statistics From Logistic Modeling of CWP 1+, CWP 2+, and PMF Against Age and Dust Exposure

	CWP 1+			CWP 2+			PMF		
	Coef-ficient	SE	p	Coef-ficient	SE	p	Coef-ficient	SE	p
Intercept	−7.5			−12.5			−13.2		
Age (years)	0.077	0.014	.0001	0.134	0.037	.0002	0.137	0.051	.007
Dust exposure ($mg\text{-}yr/m^3$)	0.015	0.002	.0001	0.016	0.004	.0003	0.013	0.006	.046
Additional effect of exposure for high rank miners ($mg\text{-}yr/m^3$)	0.009	0.002	.0001	0.014	0.003	.0001	0.017	0.004	.0001

CWP, miners of high rank coal appeared to be at additional risk. The coefficients from the logistic modeling are given in Table IV.

DISCUSSION

The limitation on airborne respirable dust in underground coal mines mandated by the 1969 FCMHSA was expected to lead to a considerable reduction in the

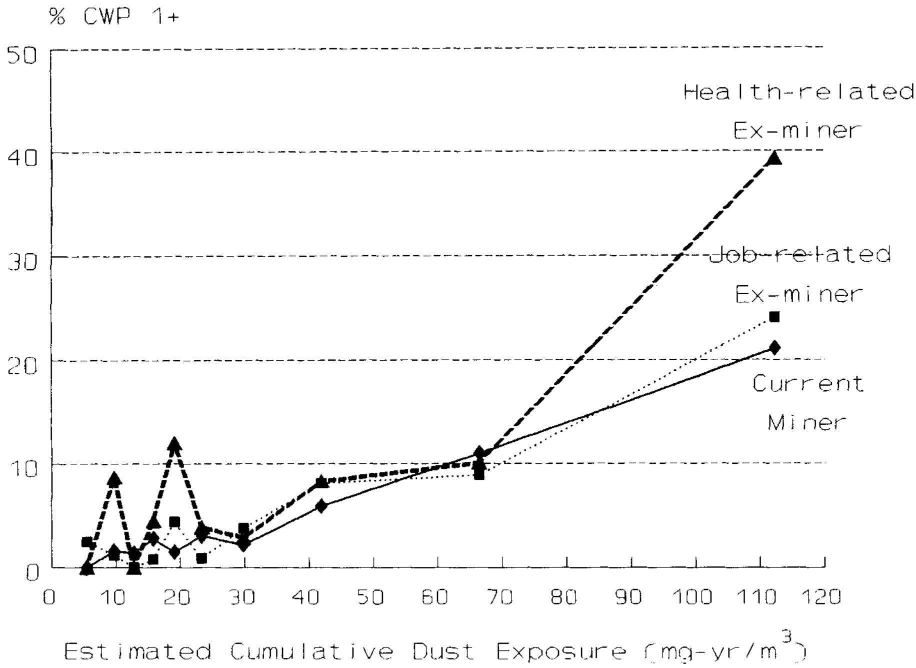

Fig. 4. Prevalences of CWP 1+ (median determinations) by deciles of estimated cumulative exposures and job status at time of medical examination.

prevalence of CWP. Analyses of the trend in prevalences of small rounded opacities over the last 20 years [Attfield and Castellan, 1992; Attfield and Althouse, 1992] confirm that there has been a decline.

Despite these encouraging findings, it would be unwise to conclude that the problem of lung disease in coal miners has been overcome. The basis for this statement can be found in Table V, which provides predicted prevalences of CWP 1+, CWP 2+, and PMF based on the modeling undertaken in this report for miners age 58 years who had worked for 40 years in coal mining at various levels of dust exposure. Of those miners who spend a working lifetime experiencing dust exposures at the current maximum of 2 mg/m^3 in the low-medium coal rank region, 14% are predicted to have CWP 1+ (95% interval estimate = 12–18%). For miners who experience half that level of dust, the predicted prevalence and 95% interval estimates are 8% and 6–11%, respectively. For CWP 2+, the predictions are 3.1% (2.0–4.9%) at 2 mg/m^3 and 1.7% (0.9–3.0%) at 1 mg/m^3, while for PMF, predictions of 1.4% (0.7–2.7%) and 0.9% (0.4–1.9%) are indicated for 2 and 1 mg/m^3, respectively. For high rank coal miners, the predicted figures are considerably greater.

It should be noted that these predictions should be treated with some caution. First, the predicted prevalences apply to ranges of age and exposure where the observed data were generally sparse (about 1% with 40 years work in mining). The danger of interpolating models near to the boundary of the data is well known. Second, the predictions are probably biased, although it is difficult to be sure to what degree. The bias arises from the combination of random and systematic factors

TABLE V. Predicted Prevalences (%) of CWP 1+, CWP 2+, and PMF at Age 58 Years After 40 Years Exposure to Various Dust Concentrations in Low-Medium Rank and High Rank Coal Mines

Dust concentration (mg/m^3)	% CWP 1+		% CWP 2+		% PMF	
	Low-medium rank	High rank	Low-medium rank	High rank	Low-medium rank	High rank
0	5	5	0.9	0.9	0.5	0.5
0.5	6	8	1.2	1.6	0.7	0.9
1.0	8	12	1.7	2.9	0.9	1.6
1.5	11	17	2.3	5.1	1.1	2.9
2.0	14	25	3.1	8.9	1.4	5.1
2.5	18	35	4.3	15.2	1.8	8.8
3.0	23	47	5.8	24.6	2.3	14.7

affecting the exposure estimates. Uncertainty intrinsic to estimation of the exposures, being due to natural variation in dust levels and to deficiencies in recalling work histories, probably led to attenuation in the exposure-response coefficient on dust exposure. This downwards bias has been offset to an unknown degree by an increase in the coefficient caused by a probable systematic underestimation of higher dust levels brought about by certain mine operator sampling practices over the years [U.S. Department of Labor, 1992]. In this respect, information from a recent study by MSHA is illuminating [U.S. Department of Labor, 1993]. This report contains the results of comparison between regular operator samples and special samples collected by inspectors. It shows that operator sampled dust levels were indeed systematically lower than those collected by inspectors during special sampling exercises. However, the bias declined with increasing size of mine, and was absent among mines employing over 125 miners. Since the NSCWP mines were all large operations, this may mean that the present analyses are not greatly affected by bias, although it may be unwise to extrapolate the recent MSHA findings to past practices.

While the use of cumulative exposure is a reasonable starting point for these analyses (and is supported to some extent by the partitioned dust exposure analysis), the current approach is not suited to the identification and assessment of possible temporal effects (e.g., residence time of dust in the lungs) and concentration effects (e.g., peak exposures) and their interaction [Seixas et al., 1993]. Moreover, the modeling approach adopted does not permit the detection of any possible threshold effects (although the results of the partitioned analysis, which reveal a relationship between exposures experienced after 1969 and CWP development, show that exposures below the legal limit of 2 mg/m^3 are not innocuous). Further study is being made of alternative modeling approaches.

The significant age term in the models has various interpretations, and may be the combined manifestation of several effects. One possibility is that there is an interaction between age and dust exposure, such that older miners require less dust exposure for development of disease. Such an interaction might be manifested as an additive effect on the logistic scale. Alternatively, age may be representing a residence time effect (in that an older miner having the same cumulative exposure as a younger miner appears to be at greater risk). Third, it is possible that the age effect may be compensating for a deficit in estimated exposure levels caused by incorrect extrapolation for the dust levels existing in the 1940s and 1950s.

In part, the age term may be representing a temporal increase in the reporting of small opacities due to a number of factors, including natural diseases, obesity, and changes in the lung parenchyma due to aging and smoking [see Dick et al., 1992 for a discussion on small irregular opacities, age, smoking, obesity, dust exposure, and other factors]. To test whether this might be the case, an alternative model was fitted in which log(exposure) replaced exposure. This particular formulation for exposure ensures mathematically that the predicted prevalence will always be zero at zero exposure, regardless of age. Comparison of the fit of the model with that obtained using untransformed dust exposure therefore provides a means of assessing whether there is an age-related effect among unexposed individuals. [This analysis was confined to the miners in the medium rank coal group for simplicity; it also used log(age − 18) to represent any other age-related effects.] Although both terms were highly statistically significant ($p<.0001$ for both), the chi-square values for each were less than those for the respective untransformed exposure and age terms. This outcome was reflected in a smaller overall log-likelihood for the log(exposure) model, implying that it provided a worse fit to the data. Hence, the evidence appears to favor the concept of an increasing rate of reporting of non-occupationally related CWP-like signs of abnormality with age. This is consistent with other reports of the same phenomenon [Castellan et al., 1985; Weiss, 1984].

Although smoking has not been found to modify the effect of dust in relation to CWP incidence [Jacobsen et al., 1977], there remains the possibility that it may be a confounding variable, in that there have been several reports linking smoking to the small irregular opacity development [see Dick et al., 1992]. This might mean that the age effect noted above is really due, in part or totally, to smoking. In order to test this hypothesis, age in the logistic model of age and dust exposure on CWP 1+ was replaced by pack-years, and the model refitted (restricted to the high volatile bituminous group for simplicity). The results showed that pack-years contributed substantially less to the model than age ($p < .10$ compared to $p < .001$), a result that does not support a link with smoking in these data.

In practice, very little solid information exists on rates of radiologically detected CWP in older unexposed workers. In a subset of 218 individuals from a study of blue collar workers who were not occupationally exposed to dust and who were aged 50 years or greater (mean age = 56 years), the prevalence of category 1/0 or greater small opacities was about 1.4% [unpublished data from Castellan et al., 1985]. Even after taking the standard error for this figure of about 0.8% into account, there is an apparent discrepancy with the figure of 5% predicted in the present report. However, the 5% prediction agrees well with a prevalence predicted for men age 60 years with zero dust exposure obtainable from interpolation of Figure 2 of Collins et al. [1988]. This indicates a 5% prevalence for category 0/1 or greater small irregular opacities (where, in fact, most [90%] of the x-rays were classified as 1/0 or greater). The inclusion of small rounded opacities, in order to derive an estimate for all opacity types, as studied in this report, would naturally raise this prediction above 5%, although it is not possible to calculate a figure from the information given.

If the observed age effect is due to non-occupational causes, the 14% prevalence of CWP 1+ among low-medium rank miners exposed to 2 mg/m^3 for 40 years would be about three times the apparent 5% background rate. Using the same rationale, the prevalence of CWP 2+ and PMF would be five and three times the background rate,

TABLE VI. Comparison of Three Sets of Predicted CWP Prevalence Estimates (%) From This Report, From Round 1 of the NSCWP [Attfield and Morring, 1992b], and From a Study of British Miners [Hurley and Maclaren, 1987]*

	Low-medium rank coal			High rank coal		
	% CWP 1+	% CWP 2+	% PMF	% CWP 1+	% CWP 2+	% PMF
1 mg/m^3 for 40 years						
This report	8	1.7	0.9	12	2.9	1.6
NSCWP Round 1	4	2.3	1.7	12	4.1	2.9
British miners	4	0.9	0.3	5	1.7	0.7
2 mg/m^3 for 40 years						
This report	14	3.1	1.4	25	8.9	5.1
NSCWP Round 1	12	4.0	2.2	28	11.5	6.5
British miners	9	2.1	0.7	11	4.1	1.8

*The figures apply to miners age 58 years who work for 40 years in 1 or 2 mg/m^3 in low-medium and high rank coals.

respectively. High rank coal miners would have a fivefold excess for CWP 1+, and a more than tenfold excess for CWP 2+ and PMF.

There are indications from Figure 4 that miners who said they left mining because of ill health had higher prevalences of CWP for given dust exposure than those who remained at work or left mining for other work. This observation was confirmed in a logistic analysis that included separate constant terms for the three groups. The greater prevalence of CWP seen in the ex-miners reinforces the need to consider ex-workers in studies of occupational disease prevalence and incidence.

One of the environmental factors missing from the present study is quartz exposure. This may have had particular relevance to certain jobs, such as roofbolter. However, reliable information on quartz levels was not available, preventing analysis of this factor. In general, this omission may not have had a severe impact on the overall findings, since studies undertaken on miners exposed generally to quartz levels below 10% of the mixed mine dust have revealed that silica appeared to play a secondary role to general coal mine dust exposure [Jacobsen et al., 1971; Hurley et al., 1982]. Quartz levels in U.S. underground coal mines are generally below 10% on average for most jobs [Tomb et al., 1986].

Table VI compares the predictions made in this report with those from two other recent studies. The first comparison study was based on data from Round 1 of the NSCWP, modeled in a similar manner to that used in the present report [Attfield and Morring, 1992b]. The second of these studies was undertaken on a large group of British miners, the predictions being derived from a compounding approach using 5-year incidence data [Hurley and Maclaren, 1987; Attfield, 1992]. The current predictions for CWP 1+ tend to be greater than those from the older studies, but all the current results for CWP 2+ and PMF lie between the two sets of estimates from the earlier studies.

Exact agreement between the different studies was not expected, because there are substantial methodological differences between them. These include, but are not restricted to: x-ray readers and ILO standards, methodological approaches adopted for exposure assessment, types of coal and mining processes, and fundamentally different methods of statistical analysis. Nevertheless, despite these differences, the findings from the three studies seem to be reasonably consistent with each other.

CONCLUSIONS

In summary, it appears that current dust conditions are leading to considerably lower prevalences of CWP than were seen in the past. However, the results described here indicate that the present coal mining work force is still at risk of developing CWP over a life time's work. These risks vary from 14% to 1.4% for CWP 1+ and PMF, respectively, for low-medium rank coal. Miners in high rank coal mining regions may be at substantially higher risks. Furthermore, it is now well established that miners are at risk from other lung diseases than CWP [Seixas et al., 1992; Attfield and Hodous, 1992]. Hence, continued efforts by all involved parties to reduce dust exposure are clearly needed in order to ensure that disease levels are minimized.

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