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The Incidence and Progression of Pneumoconiosis Over Nine Years in U.S. Coal Miners: I. Principal Findings

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Chest radiographs, taken at a 9-year interval for 1,261 U.S. coal miners, were read for pneumoconiosis side-by-side by six readers in a controlled trial. Incidence and progression of small, rounded opacities were consistent with levels predicted from dose-response curves developed by the British Pneumoconiosis Field Research interpolated at a concentration derived from U.S. compliance levels mandated over the last 9 years. The results imply that the level of pneumoconiosis in U.S. miners is being reduced through application of the current 2 mg/m^3 standard. The long developmental period for pneumoconiosis necessitates that further study be undertaken to verify this finding and to determine whether 2 mg/m^3 is an appropriate regulatory dust level for the prevention of category 2 or greater simple pneumoconiosis over a 35-year period.

Key words: coal mining, coalworkers' pneumoconiosis, dust exposure, incidence, X-ray reading

INTRODUCTION

The 1969 United States Federal Coal Mine Health and Safety Act specified, among other requirements, that the average level of respirable dust in the underground coal mine atmosphere be maintained at or below 3 mg/m^3. The same act specified that this level was to be reduced to 2 mg/m^3, effective December 1972. This level, which remains in force, ranks among the lowest compliance levels worldwide. It compares with mean levels of 6 mg/m^3 among certain facework jobs (and very much higher maximum levels) existing prior to 1970 [Jacobson, 1971].

The principal source of information upon which these regulations were based was the Interim Standards Study (ISS) of the British Pneumoconiosis Field Research (PFR) [Fay and Rae, 1959]. Of this material, critical guidance was received from what was later published as Figure 4 of Jacobsen et al [1971]. This described how the incidence of small rounded opacities of category 2/1 or greater over 35 years varied with average dust concentration. The curve showed a rising incidence of pneumoconiosis with increasing dust level, but indicated that little or no incidence was expected at 2 mg/m^3 or below. Thus it was largely on this basis that 2 mg/m^3 was adopted as the compliance level for U.S. underground coal mines.

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Since that time, further results on dose response have been produced by the PFR [Hurley et al, 1981]. These, in general, confirm the earlier findings, although they do indicate a small nonzero incidence at 2 mg/m^3. One important feature of these later results is the presence of "mine effects," which suggest that a universal dose-response curve may not be applicable to all mines. The authors of this later paper caution that this evidence suggests that their results may not be valid for other situations. This statement, of course, is applicable to the U.S. coalfields and coal miners. Since it is by no means certain that the British results apply to the U.S., their validity must be established using data on U.S. coal miners. Inquiry into this has been undertaken here using data from the National Coal Study (NCS). The NCS is a longitudinal epidemiological study, initiated in 1970 with medical surveys at 31 nationally distributed mines. Since then, two further sets of surveys have been completed, with the latter ending in 1981. The average period of time between the first and third surveys was 9 years, close to the 10 years of the ISS. Prevalence data from rounds 1 and 2 of the NCS have already been published [Morgan et al, 1973; Attfield and Hudak, 1980].

In our analyses of radiological changes in the NCS miners, radiographs of those who attended both the first and last of the three surveys were extracted. These were employed in three reading trials, the last of which involved some of the British readers who had participated in the ISS trial. Incidence and progression of coalworkers' pneumoconiosis (CWP) has been tabulated and compared to predictions made from dose-response curves published by the PFR.

METHODS

Study Group

The National Coal Study is a longitudinal investigation of the health of U.S. coalminers. In 1970, when the study began, over 9,000 miners at 31 nationally distributed mines were examined (about 10% of the workforce then). Two further rounds of surveys were held, the latter consisting of over 5,000 miners. The first and last of the surveys had 1,470 miners in common.

Examinations

The examination procedure was similar in all three rounds, and consisted of a questionnaire on symptoms, a smoking history, and work history plus demography, spirometry, and posterior-anterior and lateral X-rays. The procedures changed little over the three surveys, and for much of the time the same personnel were employed. The X-rays obtained during the surveys were read immediately after the surveys so as to inform the miners on the state of their health and to advise on transfer rights. The results from the first two rounds have been published [Morgan et al, 1973; Attfield and Hudak, 1980]. The results reported here were not drawn from those readings but were based on additional readings obtained as described below.

The Reading Trial

The X-ray readings used in this analysis were obtained using the side-by-side method. There were several reasons for this. First, there was some indication of a systematic change in film quality between rounds, possibly due to different technicians. Side-by-side reading gives the readers an opportunity to compensate for

technique differences. Secondly, and more importantly, one of the principal aims of the study was to compare incidence and progression of pneumoconiosis with that expected under the dust standard. Since the dust standard was based largely on British data where the side-by-side method was used, that method was retained to insure comparability. To ensure even greater similarity, British film readers who had previously participated in the ISS trial were recruited to read the films. The readers affirmed that they could read using the standards applicable to the ISS trials [International Labor Office, 1970], and these standards were used in this exercise.

The film-reading trial itself was organized by randomizing the 1,261 film-pairs in 13 batches. Each film pair was read by each of the six readers in a special reading exercise held over a short interval of time.

Summarization of Film Readings

This report is concerned only with the small rounded opacities and large opacities. For each of these abnormalities, a summary reading was obtained for each film. In every case this was a median reading derived from the average (rounded up to nearest subcategory) of the middle two readings of the six after they had been ranked by abnormality level.

Participation

Participation at the first survey was good (average of 90%), but subsequent surveys have seen a falling off in attendance to an average of 52% at the latest round. No ex-miners were studied; if there were systematic differences between working and ex-miners the results presented here may be biased. This is dealt with later.

RESULTS

Table I gives some statistics on the distribution of miners in the first round of the National Coal Study, on the number that participated at both rounds, and on the number of film pairs read at the side-by-side reading trial. Overall, 1,470 miners attended both the first and third surveys, but fewer film pairs could ultimately be compiled.

TABLE I. Distribution of Miners by Region and Examination

Region	First examination	Participants in both rounds	Side-by-side trial
Central Pennsylvania	455	146	98
Western Pennsylvania, Northern West Virginia, and Ohio	2,623	463	387
Southern West Virginia, Virginia, eastern Kentucky, and Alabama	2,774	449	402
Western Kentucky, Illinois, and Indiana	1,237	104	93
Colorado and Utah	983	308	281
Total	8,072[a]	1,470	1,261

[a]Out of 9,081 miners originally studied. Mines with no repeaters at the last round were omitted.

The figures indicate a substantial loss of miners to the study. To a great extent this loss was due to retirement, as the miner population studied at the first round was relatively elderly. Loss was also due to miners' leaving the area or seeking work in another mine due to mine closures and other reasons. Comparison of mine rosters with lists of participants indicated that about 50% of miners who attended the initial survey and who were still working at the same mine attended the later survey.

To explore the potential for bias in these data, certain variables were tabulated for those miners who attended both surveys of interest here, and those that attended only the first survey. Those who attended only once were found to be 5 years older on average, to have worked more years in mining (4 more years underground), and to have more pneumoconiosis (31% compared to 24%); in addition they had smoked more, had more chest symptoms, and had slightly lower ventilatory function. As these differences showed an age-dependent pattern, a repeat analysis was made stratified by age. This showed clearly that by restricting the age range from 20 to 49 years little difference existed between the "survivors" and the "leavers." The following analyses have been undertaken on both the whole group and the age-restricted subgroup.

Some information on age, tenure, and exposure is given in Table II. This group of miners was aged 40 at the first survey, had spent an average of 13 years underground prior to that survey, and had worked 80% of their inter-survey time underground.

Table III gives the results derived from median readings of the six readers. Some regression was reported. Progression rates from 0/0, 0/1, and 1/0 were 1.9, 13.6, and 18.2%, respectively, after regression was combined with the no-change category.

These statistics have been compared to levels that would be expected under the dust standard during the 9 years. Jacobsen [1973] presented curves linking the probability of progression from various starting categories over 10 years against dust concentration. These curves have been plotted and are presented in Figure 1. Some of the X-ray readers used to derive those curves were employed in the current exercise, and the reading standards used were the same.

During the 9-year period studied here, the dust levels were subject to a regulatory standard of 3 mg/m^3 for about 3 years, and for 2 mg/m^3 for the remainder. Thus, average exposure over the period was expected to be less than 2.5 mg/m^3. Interpolating the curves whose equations are shown in Table A1 of Jacobsen at 2.5 mg/m^3 indicates predicted progression rates of 2, 16, and 25% for starting categories 0/0, 0/1, and 1/0, respectively. Thus, the observed progression rates are consistent with those predicted from the data used to set the U.S. standard. This implies that they are

TABLE II. Information on Miners in the Side-by-Side X-Ray Reading Trial

Variable	No. observed[a]	Mean	S.D.
Age	1260	40	10
Years underground prior to first round	1261	13	11
Years at face prior to first round	1261	7	9
% of Time underground between surveys	1261	80	36
% of Time at face between surveys	1261	28	39

[a]Missing information causes numbers to differ.

TABLE III. Distribution of Median Determinations of Readings of Small Rounded Opacities From the Side-by-Side Trial*

	Last round of examinations										
	0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3	3/2	3/3	Total
First round of examinations											
0/0	1,112	17	3	2							1,134
0/1	11	46	5	1	2	1					66
1/0	2	7	9	3	1						22
1/1			2	7		2	1		1		13
1/2					3						3
2/1		1				1	2				4
2/2							5	1			6
2/3								1	1		2
3/2									1		1
3/3										1	1
Total	1,125	71	19	13	6	4	8	2	3	1	1,252

*Nine missing readings; mostly due to unreadable films.

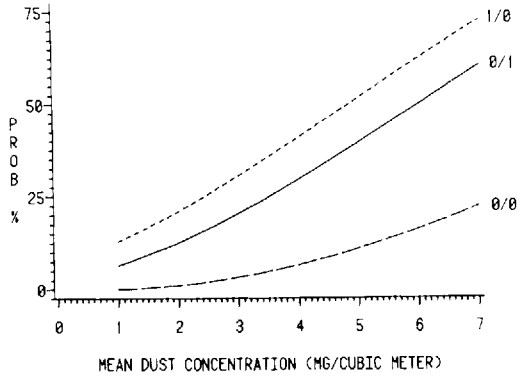

Fig. 1. Ten year predicted incidence and progression of CWP for various starting categories.

compatible with the expectation that 2 mg/m^3 should effectively prevent miners from reaching category 2/1 or greater in 35 years.

Reader variability was low, none of the readers' results being far from the median. The greatest incidence and progression rates for each starting category obtained after summarizing each readers' results separately were still close to those predicted from the dose-response curves (3.3, 21.3, and 31.4% for starting categories 0/0, 0/1, and 1/0, respectively).

The independent randomized reading trials undertaken prior to the side-by-side trial had indicated that systematic differences in technicians or technique may have led to the appearance of regression of pneumoconiosis. This possibility was pointed out independently by the readers in the latter trial. In a letter to the authors, the senior reader noted that "for a lot of the films there was a systematic technique difference," but he believed that "much of the regression would be removed at side-by-side reading provided the readings were carried out by individuals experienced in this exercise." He also added that the readers had distinguished by a special code those X-ray pairs where they believed the regression to be purely technical in nature.

To explore this point further, tabulation of the readings was undertaken omitting the readings where a reader had commented on the technical regression. After taking

medians, there was a loss of five data points. The progression indices from this dataset were 1.9, 14.1, and 26.3% for progression from 0/0, 0/1, and 1/0, respectively, after combining regression with no change. Overall, the effect of omitting these specially denoted readings did not lead to different conclusions.

Reference has been made earlier to the low participation in the latter survey and the associated problem of bias. It was pointed out, however, that for those miners aged between 20 and 49 at the first round no obvious differences existed between those who stayed on at the mine after the first examination and participated in the latter examination, and those not returning at the last examination. As a consequence, an analysis was undertaken on the subset of miners in the restricted age range.

These results are presented in Table IV. Progression from 0/0, 0/1, and 1/0 was 1.6, 11.3, and 13.3%, respectively, when regression was combined with no change. This group had a mean age of 37 years and had spent an average of 10 years underground prior to the first survey, of which about 50% was face work. Thus it appears that inclusion of the older miners, who we previously noted as being in somewhat better health than their colleagues who did not attend the latter survey, did not apparently bias the results. (This analysis includes those with "technical regression.")

Many of the older miners in the group had experienced considerable exposure to coal dust prior to the first examination. As radiological progression of CWP appears to depend both on concurrent and prior dust exposure, an analysis was undertaken of those miners having had little exposure to dust prior to the first round.

There were 505 miners with 5 or fewer years underground before the first examination. The intersurvey tenure of these miners was very similar to that of all miners shown in Table II. No net X-ray progression was detected (cases showing a movement from category 0/0 to 0/1+ minus those showing the opposite tendency). Further study over a longer period and with more observations is clearly required to verify this observation. In part, this is being done in another NIOSH study dealing with coal miners and whose results are to be published shortly (also described in part in Attfield et al, [1983].

TABLE IV. Distribution of Median Determinations of Readings of Small Rounded Opacities From the Side-by-Side Trial (Age Restricted to 20–49 Years)*

	Last round of examinations										
	0/0	0/1	1/0	1/1	1/2	2/1	2/2	2/3	3/2	3/3	Total
First round of examinations											
0/0	911	13	1	1							926
0/1	8	39	2	1	2	1					53
1/0	2	6	5	1	1						15
1/1			2	5		1	1		1		10
1/2					1						1
2/1		1				1	2				4
2/2							5	1			6
2/3											0
3/2									1		1
3/3										1	1
Total	921	59	10	8	4	3	8	1	2	1	1,017

*Nine missing readings; mostly due to unreadable films.

A discussion of radiological changes in coal miners would be incomplete without mention of large opacities, since it is this severe form of pneumoconiosis the dust standards are intended to eliminate. Five cases of large opacities were seen; one, a type A at the initial survey, did not change categories over the study period. The remaining four, according to the definitions used here, were new cases; three of these were category B at the final survey while one was an A. Simple pneumoconiosis readings at the two surveys for these four were 3/2 to 3/2, 2/2 to 2/2, 0/1 to 1/2, and 0/0 to 0/0 for small rounded opacities. The latter miner, though apparently normal regarding small *rounded* opacities, was reported as changing from 0/0 to 2/2 on small *combined* opacity readings. One miner was 48 years of age, while the remainder were aged over 55; all miners had spent most of their working lives in mining, though one of the miners had worked principally in surface jobs.

DISCUSSION

Recent evidence from the PFR indicates that the interim dose-response curve used to set the British and U.S. dust standards was valid. The data presented here provide additional evidence on the validity of the British epidemiological results. They also indicate that progression of pneumoconiosis is being controlled by the mandated regulatory level. No severe progression (ie, from category 0 to 2) was noted, and levels of progression were in the region expected under the mandated dust levels during the study period. Despite this, it would be unwise to accept these findings as the last word on the validity of the 2 mg/m^3 standard. The period of study was only 9 years; the question will be answered conclusively only by observation of the consequences of a lifetime's exposure to 2 mg/m^3.

There is some uncertainty over the validity of extrapolating these data to all U.S. underground miners. Although, at the first round, the NCS accounted for about 10% of all U.S. underground miners, the NCS miners were drawn from mines larger than average. In addition, although the NCS is spread geographically, it is not a random sample. Finally the NCS does not include all mining methods and has few miners that worked in longwall mining. For these reasons caution should be applied in extending the results to all miners.

The problem of bias deserves special comment. As there was a considerable loss of miners from the study between the two examinations, it appears that bias is a potential problem in these results. The problem may, however, be actually less than it appears. The cohort at the first round was relatively elderly; many of the older miners would have retired before the later round of examinations. Another factor to take into account is the fact that some of the mines closed before the later round, which meant that the miners at those mines did not get examined at that round. In addition, since simple CWP in its early stages (which comprises much of the abnormality seen here) is not generally associated with overt symptoms or other detectable physical signs (apart from the X-ray shadows) its presence should not have had an influence on miners not participating in the later round either directly through choice, or indirectly through leaving mining because of CWP-related ill health. Furthermore, analysis of the age-restricted subgroup of these data, a group which did not demonstrate any obvious signs of bias, suggests that the problem of bias may not be severe. Plans for future follow-up are being organized to cope with these problems of loss of workers to the study, and of regression of pneumoconiosis.

Note that, despite some impressions to the contrary, the 2 mg/m^3 standard should not be expected to eliminate all pneumoconiosis. Some incidence is predicted under the standard, although cases should be few and not severe in nature. Note also that miners who develop CWP are not necessarily protected against further progression under the current standard. There is some evidence of this in the results of the present analysis. Minimization of the numbers of miners who suffer further progression can only be achieved through successful monitoring of workers' health by schemes such as the coalminers' surveillance program administered by NIOSH, and through the miners taking advantage of the knowledge gained through participation in such schemes by transferring to less dusty jobs if CWP is detected.

The fact that four cases of progressive massive fibrosis (PMF) apparently developed during the course of this study does not vitiate the finding for simple CWP and indicate that the dust standards are ineffective. Progressive massive fibrosis usually develops only after considerable period of dust exposure, and does not demonstrate a clear dose-response relationship with exposure. All of the miners except one were approaching retirement and thus had experienced most of their dust exposure before the standards went into effect. In addition, two of the miners were among the few in the later stages of simple CWP at the initial examination which placed them at a much greater risk of developing PMF.

The question of dose-response has not been dealt with here. To what extent one can realistically expect to identify a relationship between dust exposure and radiographic changes today with these data is questionable. Not only is the dust level in a very restricted range due to dust regulation [see, for example Attfield et al, 1984b], but the available dust data are not as comprehensive as would be desired. This applies particularly to examination of dust composition and particle size distribution . In addition, X-ray readings have a high degree of variability, and this coupled with the rather low numbers indicates that a dose-response relationship may not be detectable. Insofar as it is possible, an exploration is being made currently of dust levels and other factors and their possible influence on the X-ray data reported here [Attfield et al, 1984a,b].

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REFERENCES

Attfield MD, Hudak J (1980): National Coal Study prevalence of coalworkers' pneumoconiosis: Comparison of first and second rounds. In Rom WN, Archer VE (eds): "Health Implications of New Technologies." Ann Arbor: Ann Arbor Science, pp 203–212.

Attfield MD, Althouse R, Glenn RE, Reger RB (1983): Radiological changes in U.S. coalminers over nine years. Presented at the VI International Pneumoconiosis Conference, Bochum, West Germany, September, 1983.

Attfield MD, Reger RB, Glenn RE (1984a): The incidence and progression of pneumoconiosis in U.S. coalminers: II Relationship with dust exposure and other potential causative factors. Am J Indust Med 6:417–425.

Attfield MD, Reger RB, Glenn RE (1984b): A description of the environmental data used in the National Coal Study. (In preparation.)

Fay JWJ, Rae S (1959): The pneumoconiosis field research of the National Coal Board. Ann Occup Hyg 1:149–161.

Hurley JF, Burns J, Copland L, Dodgson J, Jacobsen M (1981): Coalworkers' simple pneumoconiosis and exposure to dust at 10 British coal mines. Br J Ind Med 39:120–127.

International Labor Organization (1970): "International classification of radiographs of pneumoconioses (revised, 1968)" Geneva: ILO.

Jacobsen M, Rae S, Walton WH, Rogan JM (1971): The relation between pneumoconiosis and dust exposure in British coal mines. In Walton WH (ed): "Inhaled Particles III." Old Woking, Surrey: Unwin Brothers, pp 903–919.

Jacobsen M (1973): Progression of coal workers' pneumoconiosis in Britain in relation to environmental conditions underground. In: "Proc Conf Technical Measures of Dust Prevention and Suppression in Mines, Luxemburg, 11–13 October 1972." Luxemburg: Commission of the European Communities, pp 77 93.

Jacobson M (1971): Respirable dust in bituminous coal mines in the U.S. In Walton WH (ed): "Inhaled Particles III." Old Woking, Surrey : Unwin Brothers, pp 745–755.

Morgan WKC, Burgess DB, Jacobson G, O'Brien RJ, Pendergrass EP, Reger RB, Shoub EP (1973): The prevalence of coalworkers' pneumoconiosis in U.S. coal mines. Arch Environ Health 36:206–210.