ORIGINAL RESEARCH

Progression of coal workers' pneumoconiosis absent further exposure

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Received 10 February 2020
Revised 4 June 2020
Accepted 25 June 2020
Published Online First 11 August 2020

To cite: Almberg KS, Friedman LS, Rose CS, *et al*. *Occup Environ Med* 2020;**77**:748–751.

ABSTRACT

Objectives The natural history of coal workers' pneumoconiosis (CWP) after cessation of exposure remains poorly understood.

Methods We characterised the development of and progression to radiographic progressive massive fibrosis (PMF) among former US coal miners who applied for US federal benefits at least two times between 1 January 2000 and 31 December 2013. International Labour Office classifications of chest radiographs (CXRs) were used to determine initial and subsequent disease severity. Multivariable logistic regression models were used to identify major predictors of disease progression.

Results A total of 3351 former miners applying for benefits without evidence of PMF at the time of their initial evaluation had subsequent CXRs. On average, these miners were 59.7 years of age and had 22 years of coal mine employment. At the time of their first CXR, 46.7% of miners had evidence of simple CWP. At the time of their last CXR, 111 miners (3.3%) had radiographic evidence of PMF. Nearly half of all miners who progressed to PMF did so in 5 years or less. Main predictors of progression included younger age and severity of simple CWP at the time of initial CXR.

Conclusions This study provides further evidence that radiographic CWP may develop and/or progress absent further exposure, even among miners with no evidence of radiographic pneumoconiosis after leaving the industry. Former miners should undergo regular medical surveillance because of the risk for disease progression.

Key messages

What is already known about this subject?

- The prevalence rates of coal workers' pneumoconiosis (CWP) and progressive massive fibrosis (PMF) have increased since the late 1990s among active US coal miners. Increased exposure to coal mine dust is associated with increased disease severity and risk of progression. Little is known about occurrence of disease progression after exposure has ceased.

What are the new findings?

- Among a cohort of 3351 former US coal miners applying for benefits between 2000 and 2013, 3.3% progressed from negative chest radiographs or simple CWP to PMF, demonstrating that CWP can develop and/or progress to PMF absent further coal mine dust exposure. Nearly half of those who progressed did so in 5 years or less, including 19 of whom progressed to PMF in just 2 years. Miners who progressed were more likely to have a higher profusion of small opacities and be younger at their initial chest radiograph.

How might this impact on policy or clinical practice in the foreseeable future?

- Former coal miners should undergo regular medical surveillance because of the risk of disease progression, and healthcare providers should be aware of the possibility of disease progression in miners who have left the industry. Additionally, regulatory efforts aimed at determining safe levels of permissible exposure to respirable coal mine dust should consider data on disease progression in former miners.

INTRODUCTION

It is now widely recognised that prevalence rates of coal workers' pneumoconiosis (CWP), and its most severe form, progressive massive fibrosis (PMF), have risen to levels not seen since the 1970s in the USA. This trend has been observed among active coal miners participating in the Coal Workers' Health Surveillance Program,[1–3] as well as among former miners applying for Federal Black Lung Program (FBLP) benefits.[4] The Central Appalachian states of Kentucky, Virginia and West Virginia have seen the steepest increases in rates of this debilitating disease.[1 2 4–7]

While this alarming increase in severe disease has been well-documented, there has been scant examination of prevalence of disease progression, especially after exposure has ceased. There is a clear dose-response relationship between cumulative coal mine dust exposure and both severity and rate of progression of disease.[8] Classic CWP historically has been characterised as slowly progressive,[9] but recent reports have documented the increase in cases of rapidly progressive pneumoconiosis (RPP). RPP is defined as an increase in small opacity profusion of more than one International Labour Office (ILO) subcategory on chest radiograph (CXR) over 5 years, and/or the development of PMF after 1985, over 10 years after reduction of permissible respirable coal mine dust levels in the USA.[6 10] Recent Coal Workers' Health Surveillance Program data from active working miners who developed PMF showed that the mean time from a normal CXR

to PMF was approximately 21 years, with some progressing to PMF in less than 10 years.[11]

The US Department of Labor (USDOL) operates the FBLP which collects administrative and clinical data on former coal miners applying for benefits.[12] As part of the federal benefits claims process, former miners provide details of their coal mine employment (CME) and are offered a pulmonary evaluation by USDOL-approved examiners. Components of the evaluation include a chest radiograph, with an ILO[13] classification provided by a National Institute for Occupational Safety and Health-certified B Reader, spirometry and resting and exercise arterial blood gas testing.[12] We examined radiographic progression of disease among former US coal miners applying for FBLP benefits between 2000 and 2013 who did not have PMF at the time they left the workforce.

METHODS

Data sources

The USDOL has maintained administrative and clinical data for all FBLP claimants since 2000. The USDOL administrative data includes the claimant's age at the time of filing; state in which the claimant last worked as a coal miner; years of coal mine employment; filing date; and a record of each administrative decision in the claims process. The clinical data contain detailed information from the miners' medical disability examinations, including the dates and ILO classification of CXRs[13] interpreted by NIOSH-certified B readers.

Study population

Data on all claims for FBLP benefits between 1 January 2000 and 31 December 2013 were obtained from the USDOL. The majority of the miners who seek FBLP benefits apply only once, and therefore have only one CXR on record. If a claim is denied or withdrawn, a miner may submit additional claims with additional CXRs. To identify progression to PMF between two or more CXRs, we included only miners with two or more available FBLP medical examinations, regardless of the outcome of the benefits claims. We did not restrict the analysis to only those who were awarded benefits because, while a determination of PMF provides strong evidence of total disability under the statutes, there will be some percentage of miners who have been classified as having PMF by one or more B readers, but who may not end up receiving benefits for a variety of reasons at the end of an often long and adversarial litigation process. To reduce the likelihood of misattribution of radiographic findings to coal mine dust exposure, we excluded miners with less than 10 years of verified CME. We also excluded miners with evidence of PMF at the time of their first CXR and miners whose first and last CXRs were taken less than 2 years apart.

Data analysis

We compared the ILO classifications of the first and last CXRs associated with claims for those miners who underwent two or more FBLP examinations at least 2 years apart. Those miners whose disease category had progressed to PMF within that time period were labelled 'progressors' and those whose did not progress to PMF were labelled 'non-progressors'. PMF was defined as an ILO classification showing large opacities of category A (signifying one or more large opacities >10 mm in diameter, with a summed long axis dimension(s) of ≤50 mm); category B (signifying one or more large opacities having the sum of longest dimension(s) of >50 mm but not exceeding the equivalent area of the right upper lung zone); or category C (signifying one or more large opacities, with combined areas exceeding the equivalent area of the right upper zone). Small opacity profusion scores were classified on an 11-point scale corresponding to each minor category of profusion defined by the ILO guidelines (note the lowest two categories, ILO categories 0/- and 0/0 were combined).

Student's t-test was used to evaluate bivariate relationships between progression status and continuous variables such as age, coal mine employment tenure in years, small opacity profusion category and time between CXRs. χ^2 tests were used to evaluate differences in distribution of categorical variables. Multivariable logistic regression models were used to examine the relationship between progression and age, time between CXRs, total years of CME, geographical region and small opacity profusion category at the time of first CXR. All statistical analyses were performed in SAS V.9.4.[14]

RESULTS

Claimant population

There were 48 841 claims in the FBLP database from 2000 to 2013, representing 37 548 unique miners. There were 3351 (6.9%) miners who had multiple claims with repeat federal medical examinations with CXRs at least 2 years apart. This subset of miners did not differ substantially from the entire FBLP applicant population on measures of age and employment tenure.[15] The mean age at the time of initial CXR was 59.7 (SD 8.5) years. The average years of verified CME in this population was 22.1 (SD 7.4) years. On average, CXRs were taken 5.6 (SD 2.9, range 2 to 13) years apart. The majority (n=2599; 77.6%) of miners in this population last worked in the Central Appalachian states of Kentucky, Virginia or West Virginia. At the time of their first CXR, 41.3% of miners had a small opacity major profusion category of 1, and 5.4% had a small opacity major profusion category of 2 or 3 (table 1). At the time of their last CXR, 3.3% of miners (n=111) had radiographic evidence of PMF.

Nearly half of all miners who progressed to PMF (n=52, 47%) did so in 5 years or less, 19 of whom had progression to PMF in just 2 years. Most miners who progressed to PMF (84%) had some degree of simple CWP on first CXR. The proportion of miners who progressed to PMF increased as the major small opacity profusion at initial CXR increased. Categories 1, 2 and 3 had prevalences of 4%, 18% and 44% of progressors, respectively (table 1). Notably, of miners who had negative ILO

Table 1 Distribution of ILO profusion major category scores at initial and final imaging of former US coal miners with serial chest radiographs (CXRs) applying for benefits from the Department of Labor Federal Black Lung Program, 2000–2013

Small opacity ILO* profusion major category at initial CXR	Large opacity ILO* category at final CXR				
	n (%)	A	B	C	Total PMF n (%)
Category 0	1786 (53.3)	12	3	3	18 (1.0)
Category 1	1384 (41.3)	41	12	1	54 (3.9)
Category 2	158 (4.7)	21	5	3	29 (18.4)
Category 3	23 (0.7)	5	4	1	10 (43.5)
Total	3351	***79***	***24***	***8***	***111 (3.3)***

*Profusion categories based on the International Labour Office (ILO) guidelines for interpretation of chest radiographs for pneumoconiosis.
PMF, progressive massive fibrosis.

Table 2 Comparison of former US coal miners who developed progressive massive fibrosis from the time of their first to last chest radiograph ('Progressors') and those that did not ('Non-progressors') in the US Department of Labor Federal Black Lung Program data, 2000–2013

Variable	Progressors	Non-progressors	P value*
Age at first CXR *mean years (range)*	55.5 (39–81)	59.8 (33–89)	<0.0001
Coal mine employment *mean years (range)*	22.4 (10–45)	22 ($^{10-22\ 24-47}$)	0.63
Years between CXRs *mean (range)*	5.9 (2–12)	5.5 (2–13)	0.14
Region last workedf			
Central Appalachia	3.8%	96.2%	0.003
Rest of USA	1.6%	98.4%	

*P value based on Student's t-test for continuous variables and χ^2 test for categorical variables.
CXR, chest radiographs.

classifications initially (defined as 0/-, 0/0 and 0/1), 18 miners (1%) progressed to PMF within the 13-year study period.

'Progressors' versus 'non-progressors'

We observed no significant differences in mean CME tenure (p=0.63) or years between CXRs (p=0.14) between progressors and non-progressors (table 2). Progressors were significantly younger at the time of their first USDOL medical examination CXR than non-progressors (55.5 vs 59.8, p<0.0001). The Central Appalachian region had a significantly higher proportion of progressors compared with the rest of the USA (3.8% vs 1.6%, p=0.003).

In multivariable logistic models, small opacity profusion at initial CXR and age were the only significant predictors of progression when also controlling for region, tenure and years between CXRs (table 3). The odds of progression to PMF increased significantly for each increasing minor category of small opacity profusion at initial CXR (OR 1.73; 95% CI 1.58 to 1.90). As age at time of first CXR increases, the odds of progressing to PMF significantly decreases (OR 0.95; 95% CI 0.92 to 0.98). Odds of progression were elevated in Central Appalachia compared with the rest of the USA, although this association was not significant.

Table 3 Associations between the development of PMF ('progression') and age, coal mine employment (CME), years between chest radiographs (CXRs), geographical region and small opacity profusion at the time of first CXR*. Data from the USDOL Federal Black Lung Program, 2000–2013

	Crude*	Adjusted†
Variable	**OR‡ (95% CI)§**	**OR‡ (95% CI)§**
Age at first CXR	0.94 (0.92 to 0.96)	0.95 (0.92 to 0.98)
CME tenure (years)	1.01 (0.98 to 1.03)	1.02 (0.99 to 1.06)
Years between CXRs	1.05 (0.98 to 1.12)	1.01 (0.94 to 1.08)
Region last worked		
Central Appalachia¶	2.44 (1.33 to 4.47)	1.25 (0.66 to 2.36)
Rest of USA	*Reference*	*Reference*
Small opacity profusion	1.80 (1.65 to 1.97)	1.73 (1.58 to 1.90)

*The crude ORs and CIs are derived from bivariate logistic regression models.
†The adjusted ORs and CIs are derived from a multivariate logistic regression model that includes all covariates listed in the table.
‡OR.
§95% CI.
¶Central Appalachia includes Kentucky, Virginiaand West Virginia.
PMF, progressive massive fibrosis; USDOL, US Department of Labor.

DISCUSSION

This study demonstrates that CWP can develop and/or progress rapidly to PMF absent further coal mine dust exposure. Among 3351 former US coal miners applying for federal benefits who had serial chest radiographs between 2000 and 2013, 3.3% progressed from negative CXRs or simple CWP to PMF. Previous studies have indicated that simple CWP can progress to PMF without further dust exposure,[16–18] but this study is the first to report progression in as little as 2 years.

The strongest predictor of progression to PMF was the severity of simple CWP, or the profusion of small opacities, at the time of a miner's initial CXR. As the profusion of small opacities increases, so does the risk of progressing to PMF despite removal from exposure. This finding underscores the importance of identifying current, active miners at the earliest stages of disease and reducing or preventing further coal mine dust exposure. Importantly, however, the absence of radiographic pneumoconiosis after dust exposure has ceased does not preclude development of PMF at a later time. Our findings suggest that former coal miners, especially those with at least 10 years of coal mine dust exposure, should participate in regular medical surveillance.

Miners who were younger at the time of their initial FBLP claim were significantly more likely to progress than those who were older even after controlling for mining tenure. Miners are eligible for benefits only if their disease is found to be totally disabling, so younger miners applying for benefits may have earlier onset of disease, possibly reflecting more severe, rapidly progressing disease. These findings are consistent with another study of RPP among active US coal miners which found increased risk of progression among younger miners.[6] Cumulative dust exposure is a primary risk factor for the development of PMF,[8 19 20] as is the composition of the dust inhaled.[10] We did not observe an association between coal mine employment tenure and progression to PMF in this population. Certain job positions, such as working at the face of the mine or as a roof bolter, are associated with the development of severe disease,[7] but we were not able to assess this in the current study as detailed job histories and specific exposure data were not available.

While we did not observe significant differences in the proportion of miners who progressed by region, the highest proportion of miners to progress was seen among those who last worked in the Central Appalachian states of Kentucky, Virginia and West Virginia. This finding is consistent with national surveillance data on active miners which found the highest rates of disease progression in these three states.[11] This region is also a 'hotspot' with large clusters of PMF among working and former miners.[1 2 4] Significantly higher levels of respirable quartz reported in federal regulatory dust samples have also been observed in Central Appalachian mines compared with other US mines.[21] Increased exposure to respirable crystalline silica and changes in the composition and/or characteristics of coal mine dust in ways that promote more intense fibrogenic lung responses are thought to be major contributors to the recent increase in the prevalence of coal mine dust lung diseases, including PMF, in the USA.[7 10 22] It is possible that some of the PMF observed in our study is due in significant part to respirable crystalline silica dust contained in coal mine dust, although we are not able to readily distinguish these dust components by chest radiography.

The USDOL FBLP database is an important, if underutilised, source of data to inform our understanding on coal miners' health, but it has several limitations stemming from its purpose as a claims adjudication database rather than one designed for health surveillance. Miners are eligible for benefits only if they

are found to have totally disabling coal mine dust lung disease. The time intervals in which chest radiographs are submitted as part of the claims process are determined by administrative and procedural factors. Not all miners choose to have follow-up chest radiographs, continue in the claims process or even file a claim to begin with. Therefore the true rate at which disease progresses to PMF is still unknown. While this study included 3351 former miners with multiple chest radiographs that enabled a study of disease progression, it may not accurately reflect the larger population of former coal miners, as participation in the FBLP is voluntary and the proportion of coal miners who file for these benefits is unknown. Cumulative coal mine employment was the only exposure metric available in these data. Consequently, we were unable to analyse specific job titles or exposures that may have been associated with progressors as compared with non-progressors. Moreover, we may have missed some cases of progressive CWP by excluding miners with fewer than 10 years of exposure, though the published literature would suggest that this remains rare.

This study is the largest to date to examine the development of PMF among former US coal miners. Despite the limitations discussed above, the findings from this study support and extend findings from previous epidemiological investigations of progression to PMF among active coal miners. This work demonstrates that progression to PMF, even in those with a 'normal' chest radiograph at the end of their careers, occurs with disturbing frequency. Former miners should undergo regular medical surveillance because of the risk of disease progression even after the cessation of exposure to coal mine dust.

Acknowledgements The authors would like to acknowledge the work of Michael Chance, Gerald Delo, Tracey Teague and Bennett Stewart of the US Department of Labor Division of Coal Mine Workers' Compensation.

Contributors KSA contributed to concept design and data acquisition and was principally responsible for data analysis and manuscript preparation. KSA takes primary responsibility for the integrity of the work as a whole. LSF, CSR, LHTG and RAC contributed to concept design, data acquisition, analysis, interpretation and manuscript revision.

Funding This research was supported by funding from the Alpha Foundation for the Improvement of Mining Safety and Health, Inc, grant #: AFC113-4. The views, opinions and recommendations addressed herein are solely those of the authors and do not imply any endorsement by the Alpha Foundation, its Directors and staff.

Competing interests None declared.

Patient consent for publication Not required.

Ethics approval This study was approved by the University of Illinois Chicago Institutional Review Board, #2013–1114.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available. The data used in this manuscript is not available for public use. This analysis was performed on a de-identified data set from the US Department of Labor and was provided to the study authors pursuant a Memorandum of Understanding between the US Department of Labor and the University of Illinois at Chicago.

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