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Postexposure progression of pneumoconiosis among former Appalachian coal miners

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Abstract

Background: The prevalence of pneumoconiosis among working United States underground coal miners has been increasing for the past two decades, with the highest rates of disease observed among miners in the central Appalachian states of Kentucky, Virginia, and West Virginia. Surveillance for this disease in the United States focuses on working coal miners, who continue to be occupationally exposed to dust. This study examines the radiographic evidence for postexposure progression of pneumoconiosis in a population of former coal miners no longer occupationally exposed to coal mine dust who were seen at a community radiology clinic in eastern Kentucky.

Methods: Data were obtained and analyzed from clinical records of former coal miners who had a clinic encounter during January 1, 2017–August 1, 2019, a recorded final year of employment, and 2 postemployment digital chest radiographs. Radiographs were classified according to the International Labour Office guidelines by at least two B Readers. A final summary pneumoconiosis severity score (range, 0–13), accounting for both small and large opacities, was assigned to each chest radiograph. Progression was defined as an increase in severity score between a miner’s radiographs over time.

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AUTHOR CONTRIBUTIONS

Noemi B. Hall: analyzed and interpreted the data, led writing of the article and takes responsibility for its content. David J. Blackley, James B. Crum, Cara N. Halldin: assisted with interpreting data and writing the article. Travis Markle: assisted with acquisition and interpretation of the data. A. Scott Laney: conceptualized and designed the study and helped with data interpretation and writing.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

ETHICS APPROVAL AND INFORMED CONSENT

The NIOSH Human Research Protection Program determined this study activity to be exempt from human subject regulation under 45 CFR 46.104(d)(4)(ii).

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

Results: Data for 130 former coal miners were analyzed. All miners were male and most ($n = 114$, 88%) had worked primarily in Kentucky. Information on race/ethnicity was not available. The most common job types were roof bolters ($n = 51$, 39%) and continuous miner operators ($n = 46$, 35%). Forty-one (31.5%) miners had evidence of radiographic disease progression after leaving the workforce, with a median of 3.6 years between first and latest postretirement radiograph. A total of 80 (62%) miners had evidence of pneumoconiosis on their latest radiograph, and two-thirds ($n = 53$) of these were classified as progressive massive fibrosis (PMF), the most severe form of the disease.

Conclusions: Postexposure progression can occur in former coal miners, emphasizing the potential benefits of continued radiographic follow-up postemployment. In addition to participating in disease screening throughout their careers to detect pneumoconiosis early and facilitate intervention, radiographic follow-up of former coal miners can identify new or progressive radiographic findings even after workplace exposure to respirable coal mine dust ends. Identification of progressive pneumoconiosis in former miners has potential implications for clinical management and eligibility for disability compensation.

Keywords

coal mining; pneumoconiosis; progression

1 | INTRODUCTION

Many clinical and epidemiological features of coal workers' pneumoconiosis (CWP) have been well-documented for decades, though more recent studies have challenged some of the classical descriptions of CWP and provided a more contemporary understanding of the disease, including a broader understanding of its manifestations.^{1,2} For example, "nonclassical" pathological and radiographic presentations and rapidly progressive disease have become increasingly common among miners in central Appalachia.³⁻⁶ Recent studies have identified and characterized "rapidly progressive" CWP, but a robust understanding of the natural history of progression, and particularly postexposure progression, remains lacking as populationbased surveillance of former workers is not conducted.

Most of the research on progression of CWP in contemporary US coal miners has focused on actively working miners who continue to be occupationally exposed to coal mine dust,^{7,8} while research on disease progression in former miners who are no longer exposed to coal mine dust is limited. Postexposure progression has been previously identified in British, French, Japanese, and Korean cohorts.⁹⁻¹² More recently, one study of contemporary US coal miners applying for federal black lung program benefits, assessed postexposure progression to progressive massive fibrosis (PMF), the most severe form of CWP where large opacities (>1 cm) are identified on radiograph.¹³ This study found that 3% of former miners studied progressed to PMF at their latest postemployment X-ray examination, including 18 miners who had no evidence of CWP at their initial postemployment X-ray.

In 2016, we conducted an investigation and reported on 60 cases of PMF among current and former coal miners identified in a 20-month period in an eastern Kentucky radiology practice.⁴ As part of the clinic's standard care for patients who had previously worked

as coal miners, serial radiographs were obtained for the purposes of clinical management and to monitor progression of chronic respiratory conditions. This study assesses these postemployment serial radiographs to describe disease progression in former miners.

Postexposure progression of pneumoconiosis in the context of the current resurgence of CWP and severe CWP in Appalachian bituminous coal miners has implications for public health surveillance and prevention, clinical medicine, and workers' compensation. The purpose of this study is to examine radiographic evidence for postexposure progression of pneumoconiosis and describe factors associated with progression in a population of former coal miners.

2 | METHODS

Former coal miners seen at an eastern Kentucky radiology practice, with recorded final year of employment, a clinic encounter during January 1, 2017–August 1, 2019, and at least two postemployment digital chest radiographs available in clinic records were included in analysis. Self-reported demographics including sex, age, coal mining tenure, and most common mining job held were collected from standard patient intake forms included in clinic records.

Serial radiographs and available occupational and demographic information were deidentified before analysis. Digital radiographs were anonymized using standard software, MIRC Dicom Anonymizer. All radiographs were then classified by B Readers according to the International Labour Office (ILO) guidelines.¹⁴ B Readers are physicians who have successfully passed a National Institute for Occupational Safety and Health (NIOSH)-operated certification examination, demonstrating competence with the ILO classification system. These radiographs received a final determination using the same protocol used to make determinations for the NIOSH Coal Workers' Health Surveillance Program, by which identification of CWP requires at least two B Readers to independently agree that small pneumoconiotic opacities are present at an ILO profusion category of $>1/0$ and identification of PMF requires at least two B Readers to agree on the presence of large pneumoconiotic opacities.¹⁵ Chest radiographs were reviewed individually by a pool of six B Readers, with each radiograph receiving between two and five classifications to reach a final determination. B Readers were not provided any additional information about this study and were not informed that radiographs were sequential. A final summary pneumoconiosis severity score (range, 0–13) was assigned to each chest radiograph according to its final determination. A score was assigned to each final determination as follows: no evidence of opacities on radiograph was assigned score 0 or 1 (for small opacity profusion determinations of 0/0 or 0/1, respectively); small opacity profusion determinations of 1/0–3/+ without presence of large opacities was assigned score 2–10, and any determination with a large opacity of A–C was assigned score 11–13.

This 14-level severity score was then used to calculate change in determinations over time, taking both profusion and large opacity category into account. Former miners were divided into categories reflecting their change in determination. Progressors were defined as those individuals who had an increase in severity score between their first and latest radiographs.

Nonprogressors were those whose severity score either decreased (regressors) or remained the same (stable) between their first and latest radiographs.

Data analysis, including descriptive statistics and *t*-tests, was conducted using SAS 9.4. Differences in select characteristics were assessed between progressors and nonprogressors using pooled *t*-tests for equal variances and Satterthwaite for unequal variances. The NIOSH Human Research Protection Program determined this study activity to be exempt from human subject regulation under 45 CFR 46.104(d)(4)(ii).

3 | RESULTS

Data from 130 former coal miners who met the case definition were included in analysis. All miners were male and most worked primarily in Kentucky ($n = 114$, 88%), with the remainder having worked primarily in the neighboring states of West Virginia ($n = 5$, 4%), Tennessee ($n = 3$, 2.4%), and Virginia ($n = 1$, 0.8%); the state where the miner worked was not recorded for seven individuals (Table 1). Information on race/ethnicity was not recorded in clinic records and therefore could not be included in analysis. The most common job types were roof bolters ($n = 51$, 39.2%) and continuous miner operators ($n = 46$, 35.4%). The majority worked exclusively in underground mines (105, 80.8%), with 20 (15.4%) reporting having worked at both surface and underground coal mines. Five miners (3.8%) spent their entire careers working at surface coal mines. The mean age at end of employment was 48.2 years (range, 30–65 years), with a mean coal mining tenure of 28.1 years (range, 14–43 years). At the initial postemployment radiograph, 82 (63%) former miners had radiographs with evidence of CWP, including 41 radiographs indicating PMF.

Forty-one miners (31.5%) had evidence of radiographic disease progression after leaving the workforce, with a mean time span of 3.6 years between first and latest postemployment radiograph, and a mean category change of 3.2. Among progressors, six advanced from having no evidence of pneumoconiosis at their initial postemployment radiograph to CWP, including two miners who progressed to PMF. Among miners with CWP at their initial postemployment radiograph, 10 progressed to PMF.

Eighty-nine miners (68.5%) did not have evidence of radiographic disease progression from their first postemployment radiograph to their most recent and were categorized as nonprogressors (Table 2). Nonprogressors included 62 miners whose severity scores did not change and 27 regressors whose severity score decreased between their first and latest postemployment radiograph, with a mean category decrease of -1.8 . Twenty-six of the nonprogressors had PMF, including 24 whose initial PMF stage remained stable. Compared with those who progressed, the mean timespan between first and latest postemployment radiograph for nonprogressors was shorter (3.6 vs. 2.4 years, $p = 0.02$). No other measured demographic characteristics differed between the two groups, as both progressors and nonprogressors were males primarily employed in Kentucky. Progressors and nonprogressors also had similar working tenures (mean: 30.0 vs. 27.3 years, $p = 0.08$), similar age at end of employment (mean: 48.5 vs. 48.1 years, $p = 0.8$), and similar time from end of employment to the initial radiograph (mean: 10.3 vs. 13.1 years, $p = 0.1$). Among those whose disease progressed, 85.4% were continuous miner operators or roof

bolter operators, and among nonprogressors 70.5% were continuous miner operators or roof bolters.

4 | DISCUSSION

These findings show that postexposure progression did occur in a portion of former coal miners, supporting the potential benefits of continued radiographic follow-up postemployment. In addition to participating in disease screening throughout their careers to detect pneumoconiosis early and facilitate intervention, radiographic follow-up of former coal miners can identify new or progressive radiographic findings. Pneumoconiosis in former miners has the potential to develop and/or progress which has implications for clinical management and eligibility for disability compensation.

Currently, periodic radiographic screening is provided to all US coal miners upon entry to the industry and approximately every 5 years throughout their entire working career at no expense to the miner.¹⁶ However, this screening does not systematically extend to former workers in the industry. These data suggest that ongoing postemployment respiratory health assessments including chest imaging should be considered, particularly in former miners with a substantial exposure history (e.g., medium to long tenure, job types with high dust exposure). In 1985, Maclaren and Soutar¹² noted that continued surveillance of miners with radiographic evidence of simple pneumoconiosis after they leave the industry could identify at least two-thirds of the subsequent cases of PMF. Postemployment surveillance would provide the opportunity for miners to be aware of their potentially dynamic respiratory condition and facilitate referral to appropriate pulmonary care and evaluation for disability compensation if appropriate.

State workers' compensation programs in the Appalachian states with the highest prevalence of CWP and PMF have statutes of limitations on filing claims based on disease stage at initial diagnosis and/or date of documented last exposure.¹⁷⁻¹⁹ Workers' compensation programs differ across states but it is important for statutes of limitations for compensation claims to recognize the potential for ongoing and future progression of CWP. Otherwise, diagnosis at an early stage might confer an initial partial benefit that would be insufficient if there was future progression to greater levels of impairment including completely disabling respiratory impairment.

The Federal Black Lung Program requires successful claimants to have total respiratory disability arising from coal mine employment. Miners with no or lesser degrees of respiratory impairment should be aware that CWP can progress absent ongoing exposure and thus they may be eligible for benefits in the future even if a previous claim was denied. For example, in the present study, 29.3% (12/41) of those who had progressive disease began the study with mild to moderate disease and progressed to PMF.

This study provides insights into progression of pneumoconiosis among contemporary US coal miners and has several strengths and limitations. Progression of disease absent further exposure in contemporary US coal miners has previously only been studied as it relates to the development of large opacities,¹³ whereas this study describes progression within stages

of profusion, not limited to large opacities. Miners included in this study were patients from a single clinic, who voluntarily sought care at this location. This study population may be limited geographically by the clinic's location in eastern Kentucky, but the clinic catchment area lies within an area of central Appalachia previously identified as a hotspot of disease.^{3,4} Most miners in this study were underground coal face workers exposed to coal mine dust over many years. Though exposure could not be assessed directly, both mining tenure and job type can be interpreted as a proxy for exposure.

Though the majority of nonprogressors in this study did not have any change in their radiographic classifications over time ($n = 62, 69.7\%$), 27 miners' radiographic classifications decreased at least one subcategory. The challenges in intra and inter reader variability using the ILO classification system are well established.²⁰⁻²² Minor subcategory changes may reflect actual change in disease status or may not reflect a meaningful change in disease status due to both the subjective nature of image classification and the within and between reader variability inherent in repeated classification of serial images from a given individual. However, the classifications done in this study used an experienced pool of NIOSH-approved B Readers to minimize reader variability.

Among those whose severity category decreased over time, the mean category decrease was -1.8 . This apparent decrease is likely a reflection of slight differences in B Reader classifications due to reader variability, and not actual regression of disease. Among those whose severity category increased, the category change was 3.2 , a significantly higher absolute change for progressors compared with those who regressed (3.2 vs. $1.8, p = 0.01$).

There is currently no curative treatment for CWP. After removal from exposure CWP can remain stable or progress. Early British studies have suggested that the rate of disease progression may not be uniform across the spectrum of severity and may be slower in the earliest radiographic stages of CWP and become more rapid as small opacity profusion reaches categories two and three.^{12,13,23,24} Our findings are consistent with the hypothesis that disease progression accelerates more rapidly at advanced stages. At the initial postemployment radiograph, the average severity score among progressors was 6.3 , while average severity among nonprogressors was 4.9 ($p = 0.1$). Among progressors, 68.3% had a final determination of PMF on their final radiograph. In contrast, 14.6% ($13/89$) of the nonprogressors began and ended the study with PMF.

Development and progression of CWP occurs even absent further exposure to coal mining employment. Former coal miners may therefore be advised to take steps to continue to monitor their respiratory health, even if an initial postemployment radiograph does not identify radiographic evidence of disease. Lifelong surveillance among former coal miners, particularly those with histories of substantial exposure, may be warranted not only to protect their health, but also to reassess their level of impairment which may encourage miners to seek disability compensation and health benefits from state and federal programs even if they had previously been ineligible or denied.

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Characteristics of former coal miners seen at a Kentucky clinic, January 1, 2017–August 1, 2019

TABLE 1

Number of miners with at least two postemployment radiographs	130
Age at final year of employment (years), mean \pm SD	48.2 \pm 8.3
Male	130 (100%)
State last worked	
Kentucky	114 (92.6%)
West Virginia	5 (4.1%)
Tennessee	3 (2.4%)
Virginia	1 (0.8%)
Total tenure (years), mean \pm SD	28.2 \pm 8.1
Time in years between first postemployment radiograph and most recent radiograph, mean \pm SD	2.8 \pm 2.1
Time in years between end of employment and first postemployment radiograph, mean \pm SD	12.3 \pm 9.1
Miners with evidence of CWP at first postemployment radiograph	82 (63.1%)
Miners with evidence of CWP at most recent postemployment radiograph	80 (61.5%)
Miners with evidence of PMF at first postemployment radiograph	41 (31.5%)
A—15	
B—22	
C—4	
Miners with evidence of PMF at most recent postemployment radiograph	53 (40.8%)
A—10	
B—31	
C—12	

Note: Frequencies are presented as no. (%), miner age and time intervals presented as mean \pm standard deviation. Values were missing for some observations (4 age, 7 state worked, 1 tenure). As defined in the ILO International Classification of Radiographs of Pneumoconioses, PMF category A refers to the presence of one or more large opacities whose combined dimension is greater than 1 cm and less than 5 cm, category B refers to the presence of one or more large opacities whose combined dimension is greater than 5 cm and less than the equivalent area of the right upper lung zone, and category C refers to the presence of one or more large opacities whose size is greater than the equivalent area of the right upper lung zone. Abbreviations: CWP, coal workers' pneumoconiosis; PMF, progressive massive fibrosis.

TABLE 2
Descriptive statistics for radiographic classifications and disease progression by progression status

	Progressors	Nonprogressors	<i>p</i> Value ^a
No. miners	41	89	
Age at final year of employment (years), mean \pm SD	48.5 \pm 8.0	48.1 \pm 8.5	0.8
Total tenure (years), mean \pm SD	30.0 \pm 7.5	27.3 \pm 8.2	0.08
Time in years between end of employment and first postemployment radiograph, mean \pm SD	10.3 \pm 7.7	13.1 \pm 9.6	0.1
Time in years from first postemployment radiograph to most recent, mean \pm SD	3.6 \pm 2.9	2.4 \pm 1.5	0.02
Severity at first postemployment radiograph, mean \pm SD	6.3 \pm 4.4	4.9 \pm 5.2	0.1
Severity at most recent radiograph, mean \pm SD	9.5 \pm 4.0	4.4 \pm 5.3	<0.0001
Absolute change in severity, ^b mean \pm SD	3.2 \pm 3.1	0.6 \pm 1.0	<0.0001

Note: Miner age, time intervals, and severity scores presented as mean \pm standard deviation. Severity is based on a 14-point scale, ranging from a severity score of 0 or 1 (0/0 and 0/1, respectively, no evidence of pneumoconiosis) through all levels of small opacity profusion (severity scores of 2 through 10 for profusion scores of 1/0 through 3/+), with severity scores of 11 through 13 assigned for large opacity category A, B, and C.

^a Pooled *t*-test used for equal variances, the Satterthwaite used for unequal variance.

^b Calculated using the absolute value of change from first available to latest available postemployment radiograph.