

# Potential Determinants of Coal Workers' Pneumoconiosis, Advanced Pneumoconiosis, and Progressive Massive Fibrosis Among Underground Coal Miners in the United States, 2005–2009

A. Scott Laney, PhD, Edward L. Petsonk, MD, Janet M. Hale, BS, Anita L. Wolfe, BS, and Michael D. Attfield, PhD

In the early 2000s, during the routine analysis of surveillance chest radiographs of underground coal miners, the National Institute for Occupational Safety and Health (NIOSH) began observing several aberrations in the frequency and severity of radiographic abnormalities among underground coal miners in the United States. Specifically, the overall prevalence of coal workers' pneumoconiosis (CWP) appeared to be increasing, and NIOSH identified geographical clustering of CWP and observed rapid progression and increased disease severity, including progression to the most severe and fatal stage, progressive massive fibrosis (PMF).<sup>1,2</sup>

In response to these occupational health findings, NIOSH, with support from the US Department of Labor's Mine Safety and Health Administration, established and implemented the Enhanced Coal Workers' Health Surveillance Program (ECWHSP). ECWHSP, using a mobile examination unit in areas in which rapidly progressing CWP had been identified,<sup>1–4</sup> further assessed the initial surveillance findings, better defined the scope and magnitude of the problem and identified potentially remediable causes of the continuing development and progression of lung disease among underground coal miners.

Our focus was ECWHSP's radiographic findings consistent with CWP among miner participants. Specifically, we examined the radiographic patterns among this group of at-risk miners and investigated potential explanatory factors such as mine location and size.

## METHODS

Characteristics of the ECWHSP have previously been described,<sup>5</sup> and information about the program, including methods and

**Objectives.** We better defined the distribution and determinants of coal workers' pneumoconiosis (CWP) among US underground coal miners.

**Methods.** We obtained chest radiographs from the mobile unit of an enhanced surveillance program begun in 2005 by the National Institute for Occupational Safety and Health for underground coal miners. B Readers classified them for presence of pneumoconiosis.

**Results.** Miners from 15 states participated (n = 6658). The prevalence of CWP was higher in 3 states (Kentucky, 9.0%; Virginia, 8.0%; West Virginia, 4.8%) than in 12 other states (age-adjusted risk ratio [RR] = 4.5; 95% confidence interval [CI] = 3.3, 6.1). Miners in these 3 states were younger and had less mining tenure, but advanced CWP (category  $\geq 2/1$ ; RR = 8.1; 95% CI = 3.9, 16.9) and progressive massive fibrosis (RR = 10.5; 95% CI = 3.8, 29.1) was more prevalent among them. Advanced CWP and progressive massive fibrosis were more prevalent among workers at mines with fewer than 155 miners, irrespective of mining region, than among workers at larger mines.

**Conclusions.** Enhanced surveillance results confirmed the persistence of severe CWP among US coal miners and documented the health consequences of inadequate dust control for miners in parts of Appalachia and at smaller mines. (*Am J Public Health.* 2012;102:S279–S283. doi:10.2105/AJPH.2011.300427)

survey sites, is publicly available.<sup>6</sup> In brief, chest radiographs were taken in a mobile examination unit at or near mine sites and according to NIOSH-specified procedures, and they were classified by B Readers<sup>7</sup> for the presence, profusion, and type of lung parenchymal abnormalities consistent with pneumoconiosis using the 2000 revision of the International Labour Office's *International Classification of Radiographs of Pneumoconioses*.<sup>8</sup> The mobile examination unit met the federally mandated criteria for providing acceptable film radiographs.<sup>9</sup> We restricted the analysis to the most recent radiograph available for each individual. All participants provided informed consent.

We defined the presence of CWP as a profusion of small pneumoconiotic opacities classified as 1/0 or greater or as PMF, according to the *International Classification of Radiographs*

*of Pneumoconioses*.<sup>8</sup> We defined the presence of PMF as the recording of any large opacity interpreted as being consistent with massive fibrosis (i.e., Stage A, B, or C). On the basis of previous work, we included as a severity indicator r-type opacities, which have previously been used as a surrogate for silica exposure.<sup>10</sup> A radiograph was determined to show r-type opacities (rounded opacities between 3 and 10 mm in diameter) when the B Reader indicated r-type opacity as either primary or secondary. Multiple readings were available for each radiograph. To determine simple CWP profusion and presence of PMF, we used the NIOSH final determination, a summary measure derived from multiple classifications using a standardized procedure.<sup>2</sup> To evaluate small opacity size and shape, we used information from the most recent radiograph classification. Data were available for September 2005 through

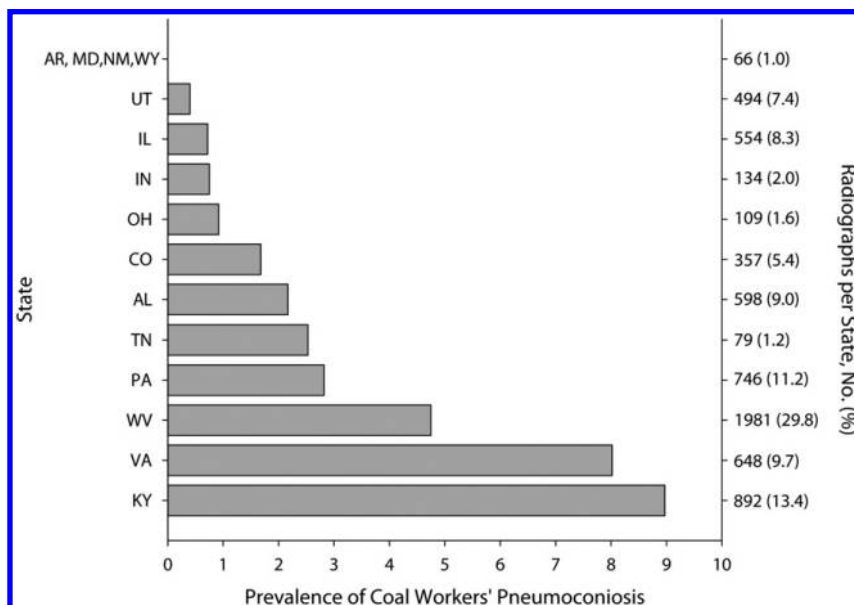
October 2009. Complete information on small opacity profusion, mine location, and employment size (mine size) was required for inclusion in the study.

We obtained mine name and location from each participating miner and determined the number of miners at the mine from reports submitted by mine operators to the Mine Safety and Health Administration. To calculate risk ratios, we categorized mine size by quartiles using the data for miners with CWP. In addition, we aggregated the data for the 3 states with highest CWP prevalence (Kentucky, Virginia, and West Virginia) and compared them with data for all other regions. This aggregation provided an approximately equal number of observations for both groupings. Because miner age is known to be associated with the presence and severity of CWP, we adjusted all disease risk ratios for miner age using log binomial regression. We compared median miner age using the Wilcoxon rank sum test. We used SAS version 9.1 (SAS Institute, Cary, NC) for all analyses.

**RESULTS**

We included 6658 ECWHSP participants from 416 mines located in 15 states. The number of radiographs collected from miners in each state is presented in Figure 1. The unadjusted prevalence of CWP varied by region and was highest in Kentucky (9.0%) and Virginia (8%) but did not differ between them ( $P = .51$ ). CWP was found in 4.8% of the radiographs of miners from West Virginia, which significantly differed from its prevalence in Kentucky and Virginia (risk ratio [RR] = 1.8; 95% CI = 1.4, 2.3;  $P < .001$ ). The prevalence of CWP in Kentucky, Virginia, and West Virginia as a group was 4 times as high as its prevalence in the other 12 states (age-adjusted RR = 4.5; 95% CI = 3.3, 6.1), although miner age (all miners) was similar in both (Table 1).

In addition to the increased prevalence of overall CWP, significantly elevated age-adjusted risk ratios were associated with other outcomes, including a higher prevalence of advanced disease (small opacity profusion  $\geq$  category 2; RR = 8.1; 95% CI = 3.9, 16.9), PMF (RR = 10.5; 95% CI = 3.8, 29.1) and r-type opacities (RR = 7.7; 95% CI = 3.8, 15.4) in Kentucky, Virginia, and West Virginia than in the 12 other states.



Note. Data from AR, MD, NM, and WY were aggregated because of the small number of radiographs contributed by miners from those states. Data in right column are number and percentage of radiographs contributed by miners from each state.

**FIGURE 1—Prevalence of coal workers' pneumoconiosis by state, sorted by prevalence: Enhanced Coal Workers' Health Surveillance Program, 2005–2009.**

**Mine Size**

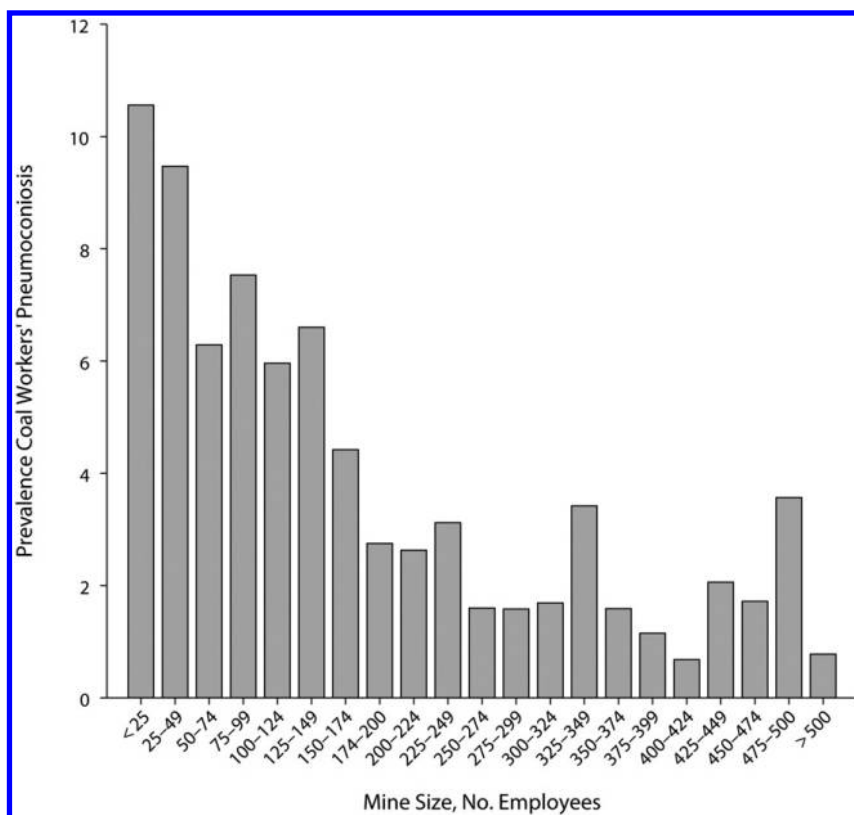
We noted a decreasing trend in CWP prevalence as mine size increased (Figure 2). However, the effect of mine size was confounded with region because the distribution of mine size differed between regions. For example, Kentucky, Virginia, and West Virginia had significantly more mines with fewer than 100 employees (46.7%) than did the 12 other coal mining states (15.1%;  $P < .001$ ).

We stratified the outcomes by region (Kentucky, Virginia, and West Virginia or the 12 other states), which showed that the prevalences of CWP, PMF, r-type opacities, and small opacity profusion of category 2 or higher for the Kentucky, Virginia, and West Virginia were significantly associated with smaller mines, although not in a linear fashion. For example, the prevalences of r-type opacities and small opacity profusions of category 2 or higher were

**TABLE 1—US Coal Workers' Pneumoconiosis by Region: Enhanced Coal Workers' Health Surveillance Program, 2005–2009**

Region	Total No.	CWP, No. (%)	RR (95% CI)	Age of Miners, Years	
				All, Mean (Median)	With CWP, Mean (Median)
12 states	3137	50 (1.6)	Ref	47.2 (50.0)	53.8 (55.0)
KY	892	80 (9.0)	7.6 (5.2, 11.0)	45.1 (46.0)	50.4 (51.0)
VA	648	52 (8.0)	6.0 (4.0, 9.1)	47.4 (49.0)	51.1 (51.0)
WV	1981	94 (4.8)	3.0 (2.1, 4.3)	47.6 (51.0)	53.6 (53.0)
KY, VA, and WV	3521	226 (6.4)	4.5 (3.3, 6.1)	46.9 (50.0)	51.9 (52.0)

Note. CI = confidence interval; CWP = coal workers' pneumoconiosis; RR = risk ratio. RR comparisons are given for Kentucky, Virginia, and West Virginia rather than prevalence of CWP as for the 12 other states included in the analysis (AL, AR, CO, IL, IN, MD, NM, OH, PA, TN, UT, WY).



**FIGURE 2—Prevalence of coal workers' pneumoconiosis by mine size (number of employees), unadjusted for age and region: Enhanced Coal Workers' Health Surveillance Program, 2005–2009.**

similar in mines with fewer than 40 miners, mines with 45–78 miners, and mines with 79–155 miners, but not in mines with more than 155 employees (Table 2). Small numbers of miners prevented a full analysis of all outcomes in the 12 other states, but the evidence showed a greater risk of overall CWP for miners in smaller mines (RR = 6.8; 95% CI = 3.3, 14.1).

### Miner Age

Consistent with the known epidemiology of CWP, increasing age was associated with CWP presence and severity. Miners working in the larger mines (> 155 miners) were slightly older (median age = 51 years; median tenure = 24 years) than miners from smaller mines ( $\leq$  155 miners; median age = 48 years; median tenure = 23 years). The median tenure of miners with CWP was equivalent among those mining in Kentucky, Virginia, and West Virginia, but it was not equivalent with that of miners in the 12 other states (30 years). However, miners

with CWP in Kentucky, Virginia, and West Virginia were younger (median age = 52 years) than miners in the other states (median age = 55 years;  $P = .01$ ), although overall the age of the workforce in the 2 regions was the same (both median ages = 50 years).

### DISCUSSION

We present an updated picture of pneumoconiosis prevalence and severity in US underground coal miners as documented through active radiographic surveillance using a mobile examination unit stationed at or near working mines. We obtained the data for this study outside of the routine NIOSH-administered Coal Workers' X-ray Surveillance Program. Our findings have confirmed recent reports that the prevalence and severity of pneumoconiosis is higher among miners in Kentucky, Virginia, and West Virginia than among miners in other parts of the United States.<sup>1,3,4,10–12</sup>

Irrespective of mining region, CWP is also more prevalent and severe among workers from smaller underground mines than among those from larger mines.<sup>5</sup>

Although mine size is associated with disease incidence, size per se is not the issue; rather, the issue is factors associated with size. Small mine size brings with it the potential for limited knowledge of, and resources for, dust reduction and disease elimination. Although larger mines can employ trained industrial hygienists and purchase state-of-the-art dust suppression measures, small mines may not have such opportunities.

The ECWHSP results have shown that not only is the disease burden greater in smaller mines, but also miners with CWP in smaller mines are younger than those in larger mines. Similarly, in some regions of the country, disease onset has been occurring in young coal miners, a finding that is not unique to NIOSH radiographic surveillance. Wade et al.<sup>13</sup> examined state compensation data between 2000 and 2009 and found that among compensated West Virginia miners, the average age at which PMF was recognized was younger than 53 years. In that study, PMF was observed in miners as young as 40 years. Given miners would have to have begun developing PMF at a younger age than when it was first identified, these findings are of great concern and demonstrate the need for further research to determine the causes.

### Strengths and Limitations

Our results have several strengths and limitations. Among the strengths are that the data were collected by a dedicated group of trained personnel in a single mobile examination unit using uniform equipment and procedures throughout the study period. All radiographs were interpreted by a minimum of 2 B Readers. All data were quality checked at the time of acquisition and verified by means of double data entry. Because participation in the monitoring program is voluntary, potential bias is a concern if those with radiographic evidence of pneumoconiosis were more or less likely than others to participate in the medical surveys. However, we are unaware of any evidence of differential participation between those with and those without radiographic evidence of pneumoconiosis. Meaningful

**TABLE 2—Prevalence of US Coal Workers' Pneumoconiosis and Progressive Massive Fibrosis and Indicators of Severity by Region and Mine Size: Enhanced Coal Workers' Health Surveillance Program, 2005–2009**

	KY, VA, and WV			Other States <sup>a</sup>		
	Sample Size (n = 3521), No.	No. (%)	RR (95% CI)	Sample Size (n = 3137), No.	No. (%)	RR (95% CI)
<b>CWP</b>						
< 40 miners	477	56 (11.7)	5.0 (3.4, 7.4)	186	11 (5.9)	6.8 (3.3, 14.1)
45–78 miners	728	67 (9.2)	3.7 (2.6, 5.4)	210	3 (1.4)	1.8 (0.5, 6.1)
79–155 miners	792	61 (7.7)	3.3 (2.3, 4.9)	212	7 (3.3)	3.0 (1.3, 6.9)
> 155 miners	1524	42 (2.8)	Ref	2529	29 (1.2)	Ref
<b>PMF</b>						
< 40 miners	477	7 (1.5)	2.3 (0.9, 5.9)	186	2 (1.1)	
45–78 miners	728	17 (2.3)	3.5 (1.6, 7.5)	210	1 (0.5)	
79–155 miners	792	10 (1.3)	2.0 (0.8, 4.7)	212	0 (0)	
> 155 miners	1524	11 (0.7)	Ref	2529	1 (0.04)	
<b>R-type opacity<sup>b</sup></b>						
< 40 miners	477	14 (2.9)	5.1 (2.3, 11.5)	186	4 (2.2)	
45–78 miners	728	25 (3.4)	5.7 (2.8, 11.9)	210	2 (1.0)	
79–155 miners	792	25 (3.2)	5.6 (2.7, 11.6)	212	2 (0.9)	
> 155 miners	1524	10 (0.7)	Ref	2529	1 (0.04)	
<b>Profusion ≥ 2/1</b>						
< 40 miners	477	12 (2.5)	3.2 (1.5, 7.0)	186	8 (4.3)	
45–78 miners	728	20 (2.8)	3.3 (1.7, 6.6)	210	1 (0.5)	
79–155 miners	792	23 (2.9)	3.7 (2.7, 11.6)	212	0 (0)	
> 155 miners	1524	14 (0.9)	Ref	2529	0 (0)	
<b>Profusion ≥ 2/1 and PMF</b>						
< 40 miners	477	16 (3.4)	3.8 (1.9, 7.5)	186	8 (4.3)	
45–78 miners	728	29 (4.0)	4.2 (2.3, 7.8)	210	1 (0.5)	
79–155 miners	792	25 (3.2)	3.6 (1.9, 6.7)	212	0 (0)	
> 155 miners	1524	16 (1.1)	Ref	2529	1 (0.04)	

Note. CI = confidence interval; CWP = coal workers' pneumoconiosis; PMF = progressive massive fibrosis; RR = risk ratio. Mine size cutoffs were based on quartiles of mine size among all miners with small opacity profusion of  $\geq 1/0$ .

<sup>a</sup>AL, AR, CO, IL, IN, MD, NM, OH, PA, TN, UT, and WY.

<sup>b</sup>We determined R-type opacities from the most recent classification of the radiograph. We calculated risk ratios using log binomial regression and adjusted for miner age. RRs are not presented for indicators of severity for other states because of instability in the estimates owing to small numbers.

differential participation by disease status seems unlikely: Recruitment efforts were directed at all miners, regardless of disease status. Moreover, miners are probably unaware that they have pneumoconiosis, at least in the less severe stages of the disease, because it often presents without symptoms.

Findings from the ECWHSP were similar to those from the Coal Workers' X-ray Surveillance Program and showed very similar tenure-specific prevalence of radiographic abnormalities (data not shown). Our results were also quite consistent with published findings based on multiple data sources.<sup>1,3,4,12–16</sup> We should note that because the ECWHSP is

restricted by federal mandate to currently employed coal miners, the findings likely represent the minimum burden of pneumoconiosis among miners and ex-miners in the areas sampled.

### Conclusions

Although the total magnitude of disease burden remains somewhat uncertain, what is known about the state of coal miner health in the United States is troubling. Our analysis, restricted to 2005–2009 data from only the active surveillance program, identified 276 working miners with CWP, 77 with advanced disease, and 49 with PMF. As highlighted

recently in commentaries by Loomis and Seaton,<sup>17–19</sup> in a contemporary mining industry, widely available dust control technologies should entirely protect miners from developing severe pneumoconiosis. Our results starkly emphasize the need for improved dust control measures and the continuing importance of active health surveillance for US coal miners. ■

### About the Authors

A. Scott Laney, Edward L. Petsonk, Janet M. Hale, Anita L. Wolfe, and Michael D. Atfield are with the Surveillance Branch, Division of Respiratory Disease Studies, National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention, Morgantown, WV.

Correspondence should be sent to A. Scott Laney, 1095 Willowdale Road, Mail Stop HG900.2, Morgantown, WV 26505-2888 (e-mail: [alaney@cdc.gov](mailto:alaney@cdc.gov)). Reprints can be ordered at <http://www.ajph.org> by clicking the "Reprints" link.

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## Contributors

A. S. Laney, E. L. Petsonk, and M. D. Attfield contributed to data analysis and writing. J. M. Hale provided programming assistance, and A. L. Wolfe participated in study design and data collection. All authors participated in the review of the article.

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## Human Participant Protection

This study was conducted with the approval of the National Institute for Occupational Safety and Health. All participants provided informed consent.

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