Work Practices and Respiratory Health Status of Appalachian Coal Miners With Progressive Massive Fibrosis

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Objective: The aim of this study was to characterize workplace practices and respiratory health among coal miners with large opacities consistent with progressive massive fibrosis (PMF) who received care at a federally funded black lung clinic network in Virginia. **Methods:** Participants were interviewed about their workplace practices and respiratory health. Medical records were reviewed. **Results:** Nineteen former coal miners were included. Miners reported cutting rock, working downwind of dust-generating equipment, nonadherence to mine ventilation plans (including dust controls), improper sampling of respirable coal mine dust exposures, working after developing respiratory illness, and suffering from debilitating respiratory symptoms. **Conclusion:** Consistent themes of suboptimal workplace practices contributing to development of PMF emerged during the interviews. Some of the practices reported were unsafe and unacceptable. Further research is needed to determine the prevalence of these factors and how best to address them.

Keywords: central Appalachia, coal mining, progressive massive fibrosis

The Federal Coal Mine Health and Safety Act (Coal Act) was signed into law in 1969 and established respirable coal mine dust standards, dust compliance sampling requirements, and medical surveillance to protect the respiratory health of coal miners. With the implementation of the Coal Act, coal mine operators were required to maintain respirable dust levels below a permissible exposure limit (PEL) and develop mine ventilation plans documenting how coal mine dust would be controlled. The Coal Act was superseded by the Federal Mine Safety and Health Act of 1977 (Mine Act), which provides authority to the Mine Safety and Health Administration (MSHA), within the Department of Labor, to develop and enforce dust control regulations in coal mines.

Under the national surveillance system required by the Coal (and subsequently Mine) Act, mine operators must offer health screening to working coal miners at no cost to the miners at entry into coal mining and then at intervals of about 5 years throughout their careers. This surveillance system is operated by the National Institute for Occupational Safety and Health (NIOSH) and is called the Coal Workers' Health Surveillance Program (CWHSP). The CWHSP provides individual coal miners with the opportunity for early detection of interstitial lung diseases (ILDs) such as coal workers' pneumoconiosis (CWP), a disease only caused by inhalation of respirable coal mine dust, and silicosis, a disease that can result from inhaling respirable crystalline silica found in coal mine dust. The CWHSP also provides population surveillance to track the burden of disease in working coal miners. Early detection is important, because continued inhalation of respirable coal mine dust increases the risk for developing progressive massive fibrosis (PMF), the most severe form of CWP and silicosis, which is incurable, disabling, and can be fatal.

After the implementation of the Coal Act, the prevalence of CWP (defined in surveillance as radiographic evidence of ILD in coal miners) and PMF among those participating in the CWHSP declined substantially. However, after the mid-1990s, the prevalence began increasing, especially among longer-tenured miners.[1] Recent reports have also identified an unprecedented resurgence of PMF among CWHSP participants in the central Appalachian states of Kentucky, Virginia, and West Virginia[2] and a large cluster of current and former coal miners with PMF receiving treatment at a clinic in Kentucky.[2,3] In early 2017, a federally funded black lung clinic network in Virginia requested assistance from NIOSH to evaluate the burden of PMF at their clinics. NIOSH staff reviewed miner health and occupational data and identified 416 miners with PMF who received care at the clinic network during January 1, 2013, to February 15, 2017.[4] This was the largest cluster of PMF cases ever reported in the scientific literature.

Previous studies have identified associations between a higher prevalence of CWP and coal rank (type of coal), mine employment size, and coal seam height,[1,5–8] but recent reports documenting large numbers of PMF cases in central Appalachia were limited to demographics and chest radiograph findings.[3,5] To gain a better understanding of the specific work practices of some contemporary Appalachian coal miners with PMF, NIOSH, in collaboration with the federally funded black lung clinic network in Virginia, conducted a case series using semi-structured interviews. We interviewed a sample of the clinic network's miners with radiographic findings consistent with PMF and characterized their occupational histories, workplace practices, and respiratory health.

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LER analyzed and interpreted the data and led writing the article. LER, JFC, JDP, and ES interviewed the miners. CS and RC coordinated recruitment of miners. KAC reviewed and analyzed spirometry. CNH, ASL, JFC, JDP, ES, KAC, and DJB assisted with interpreting data, writing the article, and conceptualization and design of the study.

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METHODS

This study was approved by the NIOSH Institutional Review Board. Initially, to focus on the most contemporary work practices, clinic staff contacted 27 miners less than 55 years old with category B or C large opacity classifications consistent with severe PMF. Six of these miners agreed to participate. Clinic staff subsequently contacted additional miners with large opacity classifications from their patient population that they believed would likely participate (without limitation on age or large opacity category). In total, 50 miners from the clinic network patient population were invited to participate in interviews about their occupational histories, workplace practices, and health outcomes. Miners who chose to participate were interviewed individually at a network clinic site by NIOSH medical and mining engineering staff after informed consent was obtained. Miners received a $50 gift card to fuel stations in the area to help offset travel expenses to the clinic on the interview day.

Miners participated in semi-structured interviews with open-ended questions conducted by one of the two interview teams. Each team consisted of one medical staff member and one mining engineer. A NIOSH physician or nurse guided medical history discussions using the CWHSP respiratory health assessment questionnaire.[9] NIOSH mining engineers developed a questionnaire they used to guide occupational history and work practice discussions. The interviews sought to acquire information about each miner's occupational history (primary job, length of time worked), work practices, respiratory health, and smoking status. Interviewers took notes during or recorded the interviews (when explicit consent was provided) to capture the miners' responses. Recorded interviews were transcribed. After the interviews, each interviewer summarized the data from their own interviews. The miner's age, mining tenure, smoking history, and reported respiratory diagnoses and symptoms were collected during interviews and verified in medical records, if available. Investigators requested respiratory medical records, including chest radiograph reports and spirometry, a type of pulmonary function test. Medical records from the clinic network and other facilities were reviewed to characterize the miners' respiratory health. If a miner participated in the CWHSP during his career, this information was also reviewed.[10] Data from interviews and medical records were compiled and analyzed using SAS 9.4 (SAS Institute, Cary, North Carolina). Common themes that were mentioned by more than one miner and noted by an interviewer were identified post hoc by the study principal investigator who reviewed all of the data.

Chest radiograph classifications completed by B Readers[11] using the International Labour Office International Classification of Radiographs of Pneumoconiosis[12] were included. Classifications from the clinic network were performed by single B Readers. Summary classifications from the CWHSP were performed by two or more B Readers, as specified in federal regulations. The ILO system classifies small opacity profusion using the range of 0/- to 3/+ and large opacities using categories O, A, B, and C. Category O findings did not have large opacity lesions. Category A large opacity classifications had one or more lesions between 1 and 5 cm. Category B large opacity classifications had one or more lesions with combined dimensions larger than 5 cm but did not exceed the area of the right upper lung zone, and a category C large opacity classification is the most severe, with one or more lesions with combined dimensions larger than category B. CWP was classified as profusion 1/0 or greater and Category A to C large opacity classifications were consistent with PMF.

Spirometry was interpreted by trained NIOSH staff using 2005 American Thoracic Society/European Respiratory Society guidelines.[13,14] Spirometry test quality was assessed using a NIOSH grading system, where both FEV_1 (forced expiratory volume in 1 second) and FVC (forced vital capacity) were reviewed. Grade "A" was given when a test contained at least three acceptable maneuvers and the two largest maneuver volumes were repeatable within 100 mL for both FEV_1 and FVC. Grade "B" tests contained at least two acceptable maneuvers with the two largest volumes being repeatable within 150 mL. Grade "C" was given when there were at least two acceptable maneuvers with the two largest volumes repeatable within 250 mL. Results with a minimum quality rating of "C" were included. Miners' FEV_1 and FVC results were compared with predicted lower limits of normal (LLN) estimates from the Third National Health and Nutrition Examination Survey (NHANES III).[15] Results of the miner's most recent valid spirometry test were categorized into the following four ventilatory patterns:

(1) Obstructive pattern: $FEV_1/FVC < LLN$; and $FVC \geq LLN$;
(2) Restrictive pattern: $FEV_1/FVC > LLN$; and $FVC < LLN$;
(3) Mixed pattern: $FEV_1/FVC < LLN$; and $FVC < LLN$;
(4) Normal pattern: absence of the above patterns.

Spirometry results were also classified according to 2005 American Thoracic Society/European Respiratory Society severity scores.[13] Miners with serial spirometry were evaluated longitudinally. Accelerated FEV_1 decline was defined as a 15% or greater decline from baseline in addition to that predicted by age over at least a 2-year period.[13,16]

RESULTS

Out of the 50 invited, 19 miners with large opacity classifications were interviewed and included in the case series. Reasons for nonparticipation were not collected. Median age at the time of interview was 58 years (range: 50 to 64 years) and median coal mining tenure was 31 years (range: 11 to 40 years). All miners were men and 11 were current or former cigarette smokers with a median of 14 pack-years (range: 7 to 37) (Table 1). None of the participants were still active coal miners at the time of the interview.

TABLE 1. Respiratory Health and Workplace Characteristics of Former Miners With Large Opacity Classifications Consistent With Progressive Massive Fibrosis (PMF), $n = 19$

Characteristics	
Age at large opacity classification, years	
Median (range)	54 (48–62)
Sex	
Men	19
Ever-smoker	11
Smoking, pack-years ($n = 11$)	
Median (range)	14 (7–37)
Mining tenure, years	
Median (range)	31 (11–40)
Time from negative to large opacity CXR, years ($n = 16$)	
Median (range)	21 (8–37)
Accelerated FEV_1 decline ($n = 8$)*	3
Reported symptoms/diagnoses	
Symptoms of chronic cough	16
Symptoms of shortness of breath	19
Diagnosis of COPD	9
Diagnosis chronic bronchitis	2
Reported decrease in physical activity	19

COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in 1 second.

*Defined as a reduction of $\geq 15\%$ of FEV_1 from baseline in addition to age-related loss within ≥ 2 years.

Health Records

Each miner had at least one (range: 1 to 7) chest radiograph classified by a B Reader. Median age at the time of their first large opacity classification was 54 years (range: 48 to 62 years). Of the miners' most recent chest radiographs, four had category A large opacity classifications, 12 had category B, and three had category C. A median of 21 years (range: 8 to 37 years) elapsed between the miners' last normal chest radiograph (16 available, Table 2) and their first ILO classification with a large opacity classification. For 14 miners, the first radiograph with an ILO classification of CWP was also the first radiograph with a large opacity classification. Sixteen miners had participated in the CWHSP at least once during their careers; eight were under the age of 30 at the time of their most recent CWHSP encounter and six had not participated in the 20 years before the end of their mining career.

Fifteen miners had at least one valid spirometry test and 11 had ventilatory impairment: four had an obstructive pattern, four had a restrictive pattern, and three had a mixed pattern. Severity of impairment is listed in Table 2. Two of the four miners with obstructive patterns, one of the four miners with restrictive patterns, and all three miners with mixed patterns were current or former smokers. Although four miners had normal spirometry, each of those miners reported difficulty breathing, cough, and decreased activity level. Eight miners had multiple spirometry tests allowing for longitudinal evaluation; three exhibited accelerated rates of FEV_1 decline.[13,16]

Respiratory Health Interviews

Twelve miners reported having respiratory symptoms before seeking care and receiving their first chest radiograph indicative of CWP (median = 4 years; range: 1 to 22). During the interview, all 19 miners reported shortness of breath on exertion and a reduction in physical activity due to respiratory symptoms. Examples of physical activity limitations included the inability to walk up a flight of stairs, push a shopping cart, and engage in family activities. Most miners ($n = 16$) reported having a regular cough. Nine miners reported a previous chronic obstructive pulmonary disease (COPD) diagnosis from a clinical care provider. Although only two miners reported a chronic bronchitis diagnosis, 13 met the classic definition with reported regular cough and phlegm production.[17] Twelve miners reported difficulty sleeping at night. Thirteen miners also reported continuing to work a median of 7 (range 1 to 15) years after first having respiratory symptoms and seven miners reported continuing to work a median of 10 years (range 2 to 25) after their first abnormal chest radiograph. In addition, five miners reported continuing to work after receiving their first radiograph with a large opacity classification for a median of 1 year (range 1 to 6).

Mining

Occupational histories (primary job, length of time worked) were recorded for a miner's entire career to the best of his recollection; most miners held one primary job the majority of their careers. The miners' primary jobs were roof bolter operator ($n = 9$), continuous miner operator ($n = 7$), shuttle car operator ($n = 1$), or a combination of those jobs ($n = 2$). Eight roof bolter operators reported regularly working downwind of the continuous miner (a machine used to shear coal) more than once per shift. Almost all ($n = 18$) miners reported that the continuous miner cut rock during their careers and 13 reported that a substantial amount of rock was cut. Six miners also reported that the continuous miner cut through sections of pure rock for extended periods of time (up to 3 months). Miners reported cutting sandstone, shale, and slate.

Fourteen miners reported that proper ventilation was not consistently maintained throughout their careers. Eight miners reported following required ventilation plans more closely when MSHA

TABLE 2. Individual Characteristics of 19 Miners With Large Opacity Classifications Consistent With Progressive Massive Fibrosis

Miner	Tenure, years	Primary Job*	Reported Continuous Miner Cut Substantial Amounts of Rock†	Most Recent Radiograph Classification‡	Time From 0/0 to Large Opacity Classification, years	Most Recent Spirometry Result§	Ever-Smoker
1	21	rbo	N	2/3 B	34	Restrictive, mild	Y
2	31	rbo	Y	2/1 B	11	NA	N
3	27	cmo	Y	2/1 B	26	Obstructive, severe	Y
4	33	cmo	Y	2/3 B	37	NA	N
5	29	Multiple	Y	2/1 C	32	Obstructive, moderate	Y
6	32	rbo	N	2/2 B	14	Obstructive, mild	N
7	38	cmo	‖	2/3 C	31	Mixed, moderate	Y
8	37	rbo	N	2/1 B	19	Normal	N
9	17	cmo	Y	3/3 B	24	Normal	Y
10	36	cmo	Y	3/3 A	25	NA	Y
11	31	rbo	Y	3/3 C	27	Mixed, severe	Y
12	40	rbo	Y	3/2 B	13	Restrictive, moderate	N
13	22	cmo	Y	2/2 B	17	Restrictive, mild	N
14	11	cmo	Y	2/1 B	¶	Normal	Y
15	15	rbo	Y	1/2 A	19	Obstructive, moderate	N
16	19	sco	Y	1/2 B	¶	Mixed, severe	Y
17	36	Multiple	Y	1/2 B	8	Normal	Y
18	39	rbo	N	1/1 A	10	Restrictive, mild	N
19	21	rbo	N	2/3 A	¶	NA	Y

*Job held for the longest time period (rbo: roof bolter operator; cmo: continuous miner operator; sco: shuttle car operator; multiple: included rbo, cmo, and/or sco).
†Mentioned cutting rock of 12 inches or more, slope/roll, or "significant" to estimate the amount of rock.
‡Numbers represent small opacity profusion and letters represent large opacity profusion.
§Normal pattern; Obstructive pattern: $FEV_1/FVC<LLN$; and $FVC \geq LLN$; Restrictive pattern: $FEV_1/FVC>LLN$; and $FVC<LLN$; Mixed pattern: $FEV_1/FVC<LLN$; $FVC<LLN$.
‖Miner did not answer.
¶Miner did not have negative radiograph to calculate time to PMF classification.
NA, not available for evaluation. Miner did not have spirometry available or spirometry did not meet American Thoracic Society guidelines.

inspectors or corporate safety personnel were present and when compliance dust sampling was being conducted. Some miners attributed this to prioritization of coal production in their workplaces. For example, one miner stated "We didn't [follow the ventilation plan] except when the inspector was [there]. I mean, they'd still ventilate but when it [the ventilation curtain] got tore down just go on 'cause you got to run coal. And if you want to keep a job, you done it."

Thirteen miners reported that personal dust samplers were not worn properly in an effort to ensure compliance with the PEL; nine miners specifically reported that the dust samplers were placed in the "intake air" or "power center," areas in the mine known to have lower dust levels. With regard to respirator use, three miners reported that they never wore a respirator, one miner reported he always wore a respirator, and 15 miners reported that they wore respirators at times or during certain work activities, such as cutting rock or operating the continuous miner.

In order to garner trust and reduce fear of reprisals, we did not ask any questions about the miners' specific employers or mines worked. Therefore, we cannot determine whether any of these miners worked at the same mine. However, informal conversations that occurred between miners before and after their formal interviews suggested that most of the miners were employed at different mines throughout the central Appalachian region during their careers.

Overall, very consistent themes emerged during the interviews and are summarized in Table 3. Due to the qualitative conversational design of the interviews, themes that were not directly prompted by questions may have emerged spontaneously during discussions. Therefore, because a miner did not mention a theme listed in Table 3 does not mean he did not experience this situation; thus, a denominator cannot be determined and results should be interpreted accordingly. To provide more individualized accounts of these miners' careers and respiratory health, we further describe the experiences of two miners with particularly detailed occupational and medical histories. These miners' experiences aligned with the themes that we documented among the 19 miners in this case series as highlighted in Table 3.

Miner 10

Miner 10 worked at multiple mines for 36 years as a continuous miner operator, auger operator, and a face boss (supervisor). He retired in 2014, at 54 years of age, and had a large opacity classification within 2 months of leaving the mines. While operating a continuous miner equipped with a fan-powered, flooded-bed dust scrubber, he reported that ventilation curtains and scrubber filters were maintained and roadways were wetted to decrease dust exposures. Miner 10 also stated the coal seam height was 26 inches when he operated the auger miner, without rock cutting. When operating the continuous miner, the coal seam height was approximately 60 inches with an additional 8 to 10 inches of rock cutting. He also reported cutting through sections of pure sandstone three separate times during his career while operating the continuous miner, with each time lasting 2 or 3 months. During that time, he reported that the continuous miner used cutting bits "by the pallet." He reported wearing a half facepiece respirator for one-third of his career and wore personal dust samplers according to compliance procedures. When asked if he had any suggestions or actions he would take to prevent CWP if he were to start a mining career today, he recommended increasing ventilation. However, later in the interview, he mentioned that it may not be possible to reduce dust exposures "because all of the big seams of coal are gone, and they're cuttin' rock everywhere, and it's just ... the silica ... It's just unreal. You can't breathe it."

Miner 10 began experiencing shortness of breath in 2002, but did not seek care because he assumed it was CWP and needed to continue working to support his family. He stated "I guess if you are a coal miner, you can expect to get some form of black lung." He sought medical care for an unrelated injury in 2014, and during his treatment, received his first abnormal computed tomography (CT) scan, which revealed evidence of CWP. He then had a chest radiograph with a large opacity classification (3/3 A). Around this same time, he was diagnosed with COPD and chronic bronchitis. He is a current smoker with a 21 pack-year smoking history. He reported having a cough for the last 20 years and shortness of breath and phlegm for the last 10 years. When asked about how his daily life has changed, he stated "I can't walk around the room without feeling like I'm passing out. I can't lift anything. I can't mow my grass. I can't pick my grandson up. I'm toast, I mean, as far as breathin'."

TABLE 3. Themes Identified Through Interviews* and Medical Record Review

Theme	Miners*
Reported continuous miner cut rock	18
Reported continuous miner cut substantial† amounts of rock	13
Did not consistently maintain ventilation	14
Reported maintaining better work practices when MSHA/corporate present	8
Improperly sampled respirable coal mine dust	13
Reported dust samplers were placed in air intake or power center	9
Did not participate in the CWHSP at recommended intervals	19
Continued to work after first abnormal chest radiograph	7

CWHSP, Coal Workers' Health Surveillance Program.

*Interviews were semi-structured to encourage conversation; some themes emerged spontaneously and not all miners where asked or provided an answer to every question. Therefore, a denominator cannot be determined and results should be interpreted accordingly.

†Mentioned cutting rock of 12 inches or more, slope/roll, or "significant" to estimate the amount of rock.

Miner 12

Miner 12 worked for almost 40 years primarily as a roof bolter operator for multiple companies. He was 53 at the time of his first classification showing a large opacity and retired at age 56. He reported that the coal seam height for most of his career was around 60 inches, with an average of 12 inches of rock. He reported that on one occasion, the continuous miner cut through 4 feet of sandstone for 1 week and the cutting bits were changed every 30 minutes. He stated that the ventilation curtain was usually only maintained to the back of the roof bolter, which would allow ventilating air to exit before reaching his location. On average, he would bolt downwind of the continuous miner twice during a shift. Miner 12 reported that ventilation plan parameters were maintained when "company" was coming, with "company" being MSHA inspectors or corporate safety personnel. He perceived his dustiest exposures occurred while emptying the roof bolter dust collector box four or five times during each shift. He reported that he wore a compliance dust sampler as a roof bolter operator. However, after receiving results that were out of compliance, the sampler was given to a different miner or hung in an area with increased ventilation. He reported that he took overtime shifts to support his family and fund a child through college.

While participating in the CWHSP, Miner 12 had a negative chest radiograph in 2000 and 1/1 small opacity profusion CWP in 2006. Miner 12 received three chest radiographs at the network clinic; category A large opacity with 2/3 small opacity profusion in 2013 and category B large opacity with 3/2 small opacity profusion in 2014 and 2016. He is a lifetime nonsmoker. During the interview, he reported recurrent pneumonia, cough, phlegm, wheeze, and shortness of breath on exertion. He was diagnosed with cor pulmonale and hypertension in 2017. Miner 12's spirometry from 2013 showed moderate restrictive impairment. He visited a medical clinic nine times in the first 6 months of 2017 to manage his respiratory symptom exacerbations and reported that he cannot lift or carry items and he becomes short of breath walking up one flight of stairs.

DISCUSSION

To our knowledge, this is the first study to interview contemporary Appalachian miners with large opacity classifications consistent with PMF and characterize not only their health but also their occupational histories and workplace practices. Miners were included in this study because they had radiographic evidence of large opacities. However, many also suffered from respiratory symptoms and impaired lung function to the point that they no longer had the ability to complete basic daily activities due to their shortness of breath. The spectrum of conditions caused by respirable coal mine dust inhalation includes COPD, which causes lung function impairment.[1,18,19] The majority of miners with spirometry results had ventilatory impairment at a level exceeding that seen within the general working U.S. population.[20,21] Miners' ventilatory impairment included obstructive, restrictive, and mixed patterns. Smoking generally contributes to obstructive or mixed patterns of impairment, found in four and three miners, respectively.[22] However, two of the four miners with obstructive patterns reported never smoking cigarettes. Conditions other than lung disease, such as obesity, can contribute to a restrictive pattern of impairment. However, we did not collect weights for this study. Many miners reported similar respiratory health symptoms, diagnoses, and activity restrictions. Most did not seek medical care at symptom onset and continued working until they learned that they had large opacities, and some even beyond that point.

Participation in the CWHSP is voluntary except for initial health screenings mandated to occur after first entering the coal mining industry. A majority of the miners in this study participated in the CWHSP at least once, mostly early in their career; none of the miners in this study participated in the CWHSP at the recommended interval of approximately every 5 years. If miners have evidence of CWP (category 1 or greater), they have the legal right to request a transfer to a position where the respirable dust levels meet a reduced standard (this is called Part 90 option). However, participation in the Part 90 option is low.[23]

Since the implementation of the Coal Act, coal mine operators have been required to comply with the federal respirable coal mine dust standards. Each coal miner in this study began mining after 1969 and thus exclusively worked under these dust standards. In 1979, approximately 19% of dust samples collected by MSHA inspectors exceeded the PEL (2.0 mg/m^3); this decreased to 3% of samples by 2003.[24] Therefore, over time, a higher proportion of samples were in compliance with the PEL. Despite this, CWP and PMF prevalence has increased since the late 1990s.[1,2] A potential explanation for this apparent dichotomy might be that reported airborne dust levels were not representative of actual exposures in mines with high levels of respirable coal mine dust.

Many of the miners we interviewed wore respirators to help decrease their respirable coal mine dust exposures. Unfortunately, respirator use did not protect them from developing large opacities. By regulation, the responsibility of maintaining safe respirable dust levels in the mines lies with the coal mine operators, not the individual miner. In general, using personal protective equipment (PPE) such as respirators is the least preferred method to control hazardous occupational exposures.[25] To reliably reduce exposures, the correct type of respirator must be worn at the correct time and must fit and function properly. Breakdowns can occur with any of these steps. This is why engineering controls to reduce respirable dust exposures to safe levels are preferred.[26]

Historically, personal dust sampling results revealed that roof bolter operator and continuous miner operator occupations were at a higher risk for coal mine dust exposures.[26] The majority of the miners interviewed primarily worked in these two occupations throughout their careers. Furthermore, many of these miners reported that exposures to respirable coal mine dust had been improperly measured in their workplaces. Since 2016, selected higher risk mining positions have been required to wear continuous personal dust monitors (CPDMs) for compliance sampling.[27] The CPDM quantifies the coal mine dust concentration in the miner's breathing zone and displays the concentration in real time on the monitor, thus allowing mine operators to immediately make production and work adjustments to prevent overexposures. With this real-time dust information, miners and operators can feel more confident in their ability to identify over-exposures and use dust suppression techniques and effectively meet the applicable dust standards during a shift.

Some miners reported cutting through sections of pure rock for up to 3 months to reach other coal seams using a continuous miner machine, a machine primarily designed to mine coal. This practice was also reported in a previous study among miners with PMF working in Kentucky.[3] Due to the hardness of rock compared with coal, the bits for a continuous miner must be changed more frequently to cut through rock. As bits wear down (Fig. 1), they begin grinding instead of cutting, causing the generation of larger quantities of dust, which can lead to increased exposures.[28] Miners reported cutting various types of rock that can contain between 5% and 100% silica.[29] Cutting rock with high concentrations of crystalline silica can lead to silicosis[30,31] and PMF. A recent study found that compared with other occupations, continuous miner and roof bolter operators' dust samples had the highest amount (both around 60%) of noncarbonate minerals, which includes silica.[32] Data have also shown that working downwind of a continuous miner can increase the silica dust levels for roof bolter operators.[33] To decrease exposures to the dust, ventilation plans often limit the time that a roof bolter operator can work downwind of the continuous miner to once per shift. However, most roof bolter operators interviewed reported working downwind of the mining machine more than once per shift. Currently, respirable crystalline silica is measured in coal mines through gravimetric respirable dust sampling with subsequent laboratory analysis of silica content and is intended to keep air concentrations of respirable crystalline silica below 0.1 mg/m^3. No approved real-time dust monitor, including the CDPM, can

FIGURE 1. Comparison of worn miner bit (left) to a new bit (right). Reproduced with permission from Pollock et al.[27]

instantaneously distinguish between coal mine dust and its crystalline silica dust fraction[24]; therefore, miners and mine operators cannot determine their exposures to crystalline silica during their shifts.

This study used a case series design and participants were largely a convenience sample of miners with large opacity classifications, from a single clinic network, and these findings represent scenarios in which coal miners developed serious, preventable disease. It is unclear how commonly the mining conditions and operating practices experienced by these miners occur in other Appalachian coal mines or other mining regions. However, very consistent themes (Table 3) about what can go wrong and lead to the development of PMF were identified from our interviews and medical record review of retired miners. Further research is needed to determine the prevalence of unsafe work practices and other suboptimal occupational health themes identified in this case-series and how best to address them to protect miners from developing PMF.

Each miner in this study has large opacities consistent with PMF resulting from overexposures to coal mine dust. Interviews identified workplace practices that were unsafe and unacceptable. The miners' symptoms and disease burden are severe and could have been prevented by limiting respirable dust exposure. Based upon interviews, in some work settings, coal production was prioritized over regularly maintaining dust control measures. With the recent rollout of the 2014 MSHA rule reducing the PEL for respirable coal mine dust, requiring new technology such as the CPDM, and expanding the CWHSP,[34] regulations are stricter and potentially more protective than ever. However, for the rule to be effective in preventing disease, the CPDM must be used by miners and operators to guide work practices and reduce dust exposures. In addition, miners must feel empowered to follow mine ventilation plans and participate in respiratory health screening throughout their careers. ''Running coal'' should never be more important than protecting miners' health.

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