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Mining tenure and job duties differ among contemporary and historic underground coal miners with progressive massive fibrosis

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Abstract

Objective: To characterize differences in mining jobs and tenure between contemporary (born 1930+, working primarily with modern mining technologies) and historic coal miners with progressive massive fibrosis (PMF).

Methods: We classified jobs as designated occupations (DOs) and non-DOs based on regulatory sampling requirements. Demographic, occupational characteristics, and histopathological PMF type were compared between groups.

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Ethical Considerations:
All coal miners recruited via outreach to clinics, physicians, and attorneys provided informed consent under study 2016–0767 (approved by the University of Illinois Chicago Institutional Review Board) and/or HS-3039 (approved by the Biomedical Research Alliance of New York [BRANY] Institutional Review Board on behalf of National Jewish Health).

Conflicts of Interest: None declared.

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

Results: Contemporary miners (n=33) had significantly shorter mean total (30.4 years vs. 37.1 years, p=0.0006) and underground (28.8 years vs. 35.8 years, p=0.001) mining tenure compared to historic miners (n=289). Silica-type PMF was significantly more common among miners in non-DOs (30.1% vs. 15.8%, p=0.03) and contemporary miners (58.1% vs. 15.2%, p<0.0001).

Conclusions: Primary jobs changed over time with the introduction of modern mining technologies and likely changed exposures for workers. Elevated crystalline silica exposures are likely in non-DOs and require attention.

Keywords

Pneumoconiosis; Silicosis; Coal workers' pneumoconiosis; Progressive Massive Fibrosis; Mining tenure; Occupational history

Introduction

Coal mine dust is a well-known cause of coal workers' pneumoconiosis (CWP). The most severe form of chronic CWP is characterized by pneumoconiotic lesions >10 mm in long axis diameter, known as progressive massive fibrosis (PMF).[1] Rapidly progressive pneumoconiosis (RPP) is defined as the development of PMF and/or an increase in small opacity profusion greater than one subcategory on chest radiograph over five years.[1] In the United States (U.S.), a resurgence of PMF and RPP has occurred over the last two decades.[2, 3] The enactment of modern dust control regulations in the U.S. with the passage of the Federal Coal Mine Health and Safety Act in 1969 resulted in significant declines in disease prevalence over several decades, which later reversed. Resurgent disease has been documented despite sustained long-term declines in respirable coal mine dust levels.[4] Increased mining of thin coals seams, a process known as "thin seam" mining, is broadly implicated in potentially causing this reversal.[5] This type of mining is associated with several factors that might have changed characteristics of respirable dust exposures including extraction of significant rock material above and below the thin coal seam(s), which could increase the relative abundance of respirable crystalline silica (RCS) and other minerals in the respirable dust fraction. Additionally, the use of more powerful modern cutting machines may have changed dust particle size distributions.[1, 4, 6–9] Changes in business practices including the operation of smaller mines, where fewer workers may perform a variety of jobs including those in relatively dusty areas, as well as longer shifts and more overtime work may also be factors.[10, 11]

Despite well-characterized associations between cumulative coal mine dust exposure and risk of CWP[12], there is relatively limited information on specific occupations and their association with severe pneumoconiosis, including PMF. In underground U.S. coal mines, work at the mine face, where coal is extracted, has been associated with higher prevalence of RPP.[6] Decades ago, higher risk of silicosis, also a form of pneumoconiosis, was recognized among tunnel drillers, roof bolters, and motormen.[13] More recently, among 138 West Virginia coal miners with PMF whose claims were approved by the West Virginia State Occupational Pneumoconiosis Board between January 2000 and December 2009, the most commonly reported primary jobs were continuous-mining machine operator (41%) and roof bolter (19%).[14]

Since 1970, U.S. federal coal mine dust control regulations have required routine workplace sampling by coal mine operators in high-risk occupations. Beginning in 1980, regulations clarified that samples for both total dust and for quartz (one form of RCS) were required in designated areas (DAs) where miners routinely work and for high-dust exposure designated occupations (DOs).[5] Based on dust sampling conducted by the U.S. Mine Safety and Health Administration (MSHA) between 1982 and 2017 in underground coal mines, primarily in DOs, Doney et al., 2019 found that jobs working largely at the face had the highest mean respirable dust concentrations. These jobs included longwall workers, continuous miner operators and helpers, and cutting machine operators and helpers, as well as augerers and roof bolters.[4] Among surface coal miners, drillers and blasters had significantly higher prevalence of CWP and PMF compared to those with other job duties.[15]

Major advances in underground mining technology beginning in the 1950s have drastically changed the productivity of U.S. mines[16] and changed exposures for workers[10]. We hypothesized that miners not working in designated occupations (non-DOs) may also be exposed to high levels of RCS due to these advancements in technology, shifts to work in smaller mines, and other changing work practices that perhaps were not as relevant or considered when the respirable dust sampling standards were promulgated.

Lacking reliable dust exposure data collected in all areas of mines throughout the course of miners' careers, we examined available lung tissue from U.S. underground coal miners with PMF to investigate differences in histologic type of PMF and performed mineralogic analysis of lung dust burden for a subset of cases.[1] This study extends our previous analyses to evaluate mining tenure and job duties as they relate to the miners' lung pathology. We stratified cases as contemporary (born in or after 1930 and likely working primarily after mechanized mining methods were adopted in the U.S.) versus historical (born before 1930 and likely working primarily before modern dust control regulations and mining methods).[1, 17, 18] We hypothesized that mining tenure and job duties would differ between contemporary and historic coal miners with PMF, and that these job duties would be linked to higher degree of exposure to RCS as determined via histopathologic assessment of PMF type.

Methods

Data Sources:

Lung specimens and occupational history data were collected via two sources: 1) outreach to federally funded Black Lung Clinics, miners' physicians and attorneys, and 2) from the National Coal Workers' Autopsy Study (NCWAS). A flowsheet describing case selection is included as Figure 1.

All coal miners recruited via outreach to clinics, physicians, and attorneys provided informed consent under study 2016–0767 (approved by the University of Illinois Chicago Institutional Review Board) and/or HS-3039 (approved by the Biomedical Research Alliance of New York [BRANY] Institutional Review Board on behalf of National Jewish Health). Detailed medical, smoking, and exposure history information was collected via a Research Electronic Data Capture (REDCap) survey housed at the University of Illinois Chicago.[19]

The remaining cases were identified through the NCWAS database. NCWAS was developed by the National Institute for Occupational Safety and Health (NIOSH) in 1969 under Title 42 of the Federal Coal Mine Health and Safety Act.[20] The original purposes of the NCWAS were 1) to aid surviving relatives of deceased coal miners in establishing eligibility for federal black lung benefits and 2) to facilitate research on detection and prevention of CWP.[21] Surviving relatives were asked to complete a nine-question occupational and medical history which included information about the miner's coal mining and smoking. Until approximately 1996, NIOSH pathologists or NIOSH contracted pathologists reviewed each of the lung autopsy specimens for presence or absence of PMF and other histopathological findings. For NCWAS cases accessioned in 1996 and later, F.H.Y.G. and M.O. reviewed slides for the presence of or absence of PMF. For the current study, the archived blocks from NCWAS PMF cases were evaluated (by F.H.Y.G., A.H., and M.O.) to determine if adequate material was available for this study. Where adequate material was available, slides received additional evaluation by a team of pathologists for classification of PMF type as described below.

Determination of PMF and classification of PMF type:

PMF was defined as a dust-related fibrotic lesion measuring greater than one centimeter in longest dimension with irregular or whorled collagen fibers, with or without necrotic areas, and presence of dust consistent with coal mine dust.[12] Details of PMF type determination have been described previously.[1] Tissue specimens were reviewed by experienced teams of occupational pulmonary pathologists (F.H.Y.G., A.F., C.C., J.M., N.V., J.L.A., S.S.). Briefly, three individual pulmonary pathologists (J.L.A, S.S., and C.C.) and two pairs of pathologists (F.H.Y.G./A.F. and J.M./N.V.), blinded to whether cases were contemporary or historic, reviewed brightfield images for each case and classified each as: (1)"coal"-type of PMF defined as having ≤25% silicotic nodules; (2) "silica"-type PMF defined as having >75% silicotic nodules; (3) "mixed"-type of PMF having >25% and ≤75% silicotic nodules; or (4) "other"-type of PMF. All discordant cases were reviewed in consensus and a final designation was assigned.

Cases from underground coal miners where three or more pathologists agreed on presence of PMF were included in this analysis (see Figure 1).

Occupational History Assessments:

We obtained occupational histories from subjects recruited through outreach sources, including detailed job descriptions for each mine where they worked. Detailed personal work histories were unavailable for some miners, so data were supplemented with information from medical and workers' compensation claim documents, or via interviews with a spouse or other family member. Job descriptions obtained through these mechanisms were mapped by knowledgeable occupational health experts (C.S.R., L.Z., R.A.C. and L.H.T.G.) to align with NCWAS job codes (Supplemental Table 1). Total years of underground and surface mining were calculated by adding the time worked at each mine. The principal mining job title (or longest held job) and last job held in the mine were identified for each participant.

It was not practical to locate and interview families of subjects drawn from NCWAS. Therefore, previously recorded data from the NCWAS were used, including total years of underground and surface mining, last job title, principal job title, and the name and location of the last mine where the participant worked. We obtained copies of the original NCWAS questionnaires to confirm these data. Two investigators familiar with mining terminology (L.Z. and L.H.T.G.) reconciled discrepancies between the NCWAS database and questionnaires for years of mining as well as principal and last job descriptions. We performed a sensitivity analysis to evaluate the original database assignments for confirmation.

We classified jobs for respirable dust exposure based on MSHA regulations (30CFR§70.208) into high-risk designated occupations (DOs), those not designated high risk (non-DO), or unknown. Designated areas associated with a specific job were also included as DOs.[4] A full list of code assignments is included in Supplemental Table 2. Additionally, to explore how use of modern mechanized equipment may have changed exposures at the face, we classified those with a principal job of "cutting machine operators and helpers" or "continuous mining machine operators and helpers" as mechanized face workers, and those with a principal job of "hand loaders, coal diggers, general miners" as non-mechanized face workers.

Cases were classified as either contemporary or historic based on the miner's year of birth. Contemporary miners were those born in 1930 or after and were assumed to have worked largely after the introduction of mechanical mining. Historic miners were those born before 1930. Only participants with primarily underground mining work (principal job codes L000 through L039) were included in this analysis.

Statistical Analysis:

We used SAS (version 9.4; SAS Institute, Cary, NC) for all analyses. Categorical variables were compared between historical and contemporary groups and by PMF type using Chi-Square tests or Fisher's exact tests, where appropriate. Continuous variables were examined across historical and contemporary groups using t-tests with the Satterthwaite results presented. Particle concentrations and percentages were compared across job designations using ANOVA tests, with the p-value from the overall F-test reported. A p-value ≤ 0.05 was considered significant.

Results

This study included 11 contemporary underground miners with PMF that were recruited through outreach efforts and 311 underground miners with PMF from the NCWAS database (22 contemporary, 289 historic). All miners were male, the population was primarily white (89%), and 64% had ever smoked cigarettes, with mean pack-year history of 22.5 ± 19.3. Smoking history and race were not significantly different between historic and contemporary miners (Table 1). All historic cases came from the NCWAS dataset where tissue was obtained from autopsy, whereas 79% of tissue samples were obtained from contemporary miners via autopsy (mean age 59.6 at autopsy). This difference in the source of tissue may account for the significant difference between groups in age at tissue collection (72.2 years historical vs. 60.6 years contemporary, $p<0.0001$) or reflect younger disease onset.

As shown in Table 1, contemporary miners had significantly shorter mean total mining tenure (30.4 years vs. 37.1 years, $p=0.0006$) and mean underground mining tenure (28.8 years vs. 35.8 years, $p=0.001$) compared to historic miners. Using the original underground mining tenure data recorded in the NCWAS database instead of the separately confirmed tenure data in a sensitivity analysis, contemporary miners were still found to have worked significantly less time underground (28.5 years contemporary vs. 35.4 years historic, $p=0.002$).

While the majority (61%) of historic coal miners had worked underground in Pennsylvania, the largest proportion of contemporary miners worked underground in West Virginia (42%). A larger proportion of contemporary miners worked in DOs for the majority of their careers (67%) compared to historic miners (57%), but this difference in proportions was not significant.

We were unable to make DO assignments for 28 (8.7%) miners (25 historic, 3 contemporary) where the primary job was reported simply as “work in an underground coal mine” and for 35 (10.9%) miners (33 historic, 2 contemporary) that had no occupational history data (see Table 2). Excluding those with unknown DO assignments (n=63), contemporary cases were slightly more likely to have worked in a DO (78.6% vs. 70.6%, $p=0.38$). A sensitivity analysis examining the distribution of DOs across the historic and contemporary cases using the original assignments in the NCWAS database did not significantly change the results.

The number and percentage of contemporary and historic miners by principal job title is shown in Table 2. Among historic miners, the most commonly reported principal job titles besides the general title of “hand loaders/coal diggers/general miners” were motormen/brakemen (11.1%), continuous mining machine operators and helpers (9.0%), and work at the face/jacksetter (9.0%). Among contemporary miners, continuous mining machine operators and helpers (27.3%), roof bolters and helpers (15.2%), and work at the face/jacksetter (12.1%) were commonly reported. Among all 322 miners, 156 (48.4%) reported a different last-held job than their primary job, and 47 (14.6%) had switched from a DO to a non-DO for their last job before leaving mining. The late career change from DO to final non-DO job was similar between historic miners (n=42, 14.5%) and contemporary miners (n=5, 15.2%).

Among those in the DO category, 51 miners (41 historic, 10 contemporary) had a principal job at the face that was mechanized, and 69 miners (67 historic, 2 contemporary) had principal jobs at the face that were non-mechanized. While looking at workers with typically higher risk of silicosis[13] was also of interest, the number of roof bolters (7 historic, 5 contemporary) and motormen (32 historic, 1 contemporary) was small, and tunnel work was not a designation available in our dataset, limiting our ability to reliably investigate changes over time.

Contemporary coal miners were significantly more likely to have silica-type PMF than their historic counterparts (58.1% vs 15.2%, $p<0.0001$) (Table 3). Pairwise comparison testing indicated that silica-type PMF was significantly more common than either mixed- or coal-type PMF among contemporary miners compared to historic miners ($p<0.0001$ for both comparisons). Miners that worked primarily in non-DO jobs were more likely to have silica-type PMF while those in DOs were more likely to have coal- or mixed-type PMF ($p=0.03$) (Table 3). Miners with a principal job at the face that was mechanized were more likely to have silica-type PMF compared to miners with non-mechanized jobs (19.6% vs. 5.8%, $p=0.05$) (Table 3). Contemporary roof bolters had silica-type PMF (n=4) or other-type PMF (n=1) while historic roof bolters (n=7) had coal-type PMF (n=3) or mixed-type PMF (n=1) (data not shown).

Discussion

We found that contemporary miners with PMF worked significantly less time in mining and mined underground for an average of seven years fewer than their historic counterparts. Additionally, we observed trends in the types of jobs that historic and contemporary miners work, with a shift toward mechanized mining methods that have greater potential for more crystalline silica exposure at the face.[8, 10] In this relatively large study population of miners with PMF, we also found silica-type PMF to be significantly more common among contemporary miners and among miners working in jobs that were not designated as high risk (i.e., non-DOs) under current regulations. Our findings underscore the important role of exposure to respirable crystalline silica in PMF, and the need to sample for RCS more broadly in underground coal mines, not just for designated occupations.

In general, previous studies have shown that longer coal mining tenure (>=25 years) has been associated with higher prevalence of coal workers' pneumoconiosis[7, 22], presumably related to higher cumulative coal mine dust exposure. In contrast, our data show that contemporary miners had shorter coal mining tenures, consistent with previous reports of significantly shorter mining tenure among contemporary Central Appalachian coal miners with severe pneumoconiosis, and likely reflecting exposure to higher respirable dust and/or RCS concentrations.[23, 24] Since we do not have data about time to diagnosis or date of development of PMF, we cannot be certain that the PMF in contemporary miners meets the definition of rapidly progressive pneumoconiosis[6], but this question is important for future work.

In addition to tenure, we observed trends in the types of jobs performed by historic and contemporary miners. As anticipated, a greater proportion of contemporary miners worked in DOs compared to historical miners (66.7% vs. 56.6%), and many worked with mechanized equipment such as the continuous miner machine. Major advances in underground mining technology have drastically increased productivity[16] and as a result increased dust exposure[8, 10]. Between 1983 and 1995, longwall mines more than doubled their share of total underground production (20% vs 45%).[16] Operations using continuous miners also became much more efficient.[16] These new technologies reduced the downtime between unit operations[16], and likely altered exposures for workers. Moreover, the development of powerful modern mining machines has enabled mining in challenging geologic conditions, such as thin or variable coal seams, as well as their use in mine development such as cutting slopes to the coal face. This often involves cutting a large amount of rock along with the coal, which has caused many mines in Central Appalachia to exceed applicable dust standards for silica content.[10] Between 1982 and 2017, 18.7% of samples for respirable quartz exceeded the applicable standards, especially in Central Appalachia.[4]

Recently published work showed that the measured percentages of silica and aluminum silicates (among all classified particles) *in situ* was significantly higher among contemporary miners compared to historic miners.[1] In the current study, while contemporary miners were somewhat more likely to work in DOs, 30.1% of non-DOs had silica-type PMF. This suggests that dust sampling only in DOs may not be adequately protecting miners from exposure to RCS. In addition to real-time total respirable dust monitoring which is achievable using the continuous personal dust monitor (CPDM), capabilities for real-time RCS monitoring can enable workers to make timely decisions to reduce their exposures.[5]

Analyses of the type of PMF further support the hypothesis that silica exposure may be driving the resurgence of PMF in contemporary miners. Our findings show that 18/31 (58.1%) contemporary miners had silica-type PMF. Notably, miners that worked primarily in non-DO jobs were more likely to have silica-type PMF while those in designated occupations were more likely to have coal- or mixed-type PMF. Consistent with recommendations in the 2018 National Academies of Sciences report titled "Monitoring and Sampling Approaches to Assess Underground Coal Mine Dust Exposures", this finding demonstrates the importance of "conduct[ing] studies to evaluate the exposures of miners not wearing CPDMs to ensure that the approach of detecting and mitigating high-exposures for designated occupations reliably results in mitigating high exposures of all workers".[5]

Our study has several strengths, including access to a large repository of lung tissue from former coal miners along with information on exposures and job duties for contemporary and historical miners. Additionally, we were able to utilize and enhance a currently existing database by assigning job codes and confirming years employed during a single consistent review compared to data entry into the NCWAS database over time with changing forms and staff.

Our study also has several limitations. First, the design of the study precludes strong conclusions regarding causal inference. Serial chest imaging was not available for these cases to determine disease latency, perhaps leading to ascertainment bias that could confound the analysis of mining tenure. Moreover, detailed individual job data for cases from the NCWAS database were not available beyond what was reported by next of kin, allowing DO work status determination based only on the longest held and last job. Other sources of bias could include referral and selection bias, with contemporary miners less likely to have autopsies performed due to the availability of high resolution chest imaging, and historic miners having to have lived longer to be included in a database (NCWAS) that did not begin until 1970. Selection bias also may have resulted from changes in inclusion methods for the small number of contemporary cases due to very few NCWAS autopsies available after 2012 requiring recruitment though outreach to federally funded Black Lung

Clinics, miners' physicians and attorneys. Notably, the majority of historic underground coal miners worked in Pennsylvania while the largest proportion of contemporary miners worked in West Virginia. While the region of Pennsylvania where these miners worked is unknown, higher coal rank (as is present in eastern Pennsylvania) is associated with higher risk of CWP and PMF.[6, 25] This may have led to some temporal variability in coal rank and coal seam thickness, conferring differential risk for PMF between historic and contemporary miners in addition to job duties.

Importantly, our findings suggest that current regulatory approaches to monitoring respirable coal mine dust concentrations only in DO/DA may not accurately reflect the exposures of all miners. Our data also underscores the hypothesis that silica is a key factor in the resurgence of PMF among U.S. coal miners.[1, 3, 7] Future investigation will focus on identifying the broad spectrum of risk factors associated with increased rates of radiographic progression and physiologic decline among U.S. coal miners (e.g., job titles, mining tenure, mining region, and demographic risk factors) to inform prevention efforts. Methods to accurately and efficiently characterize and quantify *in situ* particulate matter lung burden are also being explored. Finally, advanced capabilities that enable real-time measurement of RCS along with effective exposure control responses are essential for prevention of coal mine dust lung disease.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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SMART Learning Outcomes (LC)

1. Characterize differences in mining jobs and tenure between contemporary and historic coal miners with progressive massive fibrosis (PMF).
2. Evaluate whether silica-type PMF is more common in certain coal mining jobs in historic compared to contemporary coal miners.
3. Examine if known high risk coal mine jobs (designated occupations, DO) are more likely to confer risk for PMF compared to lower risk (non-DO) jobs.

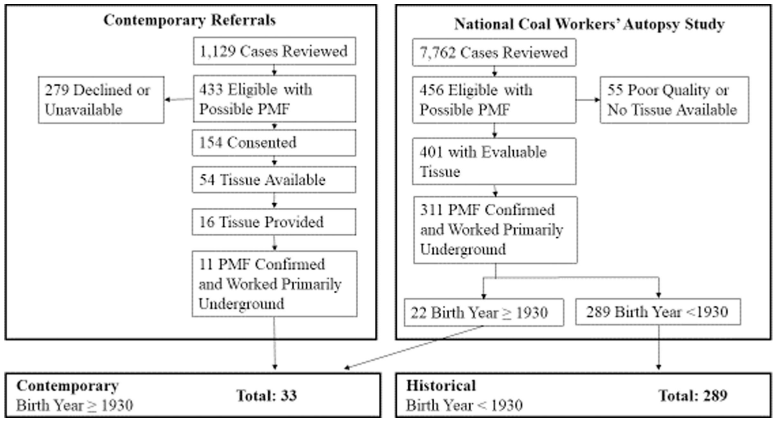

Figure 1:
Flowchart of study sample selection

Table 1:

Differences in demographic, smoking, and workplace characteristics between U.S. underground coal miners with PMF born before (historic) and after 1930 (contemporary)

	# Missing	Historic n = 289	Contemporary n = 33	p-value
Demographics and Smoking				
Age at tissue collection (years), mean (SD)	0	72.2 (8.2)	60.6 (8.7)	**<0.0001**
Tissue from autopsy, n (%)	0	288 (100%)	26 (79%)	**<0.0001**
White, n (%)	19	256 (89%)	29 (88%)	0.08 [+]
Ever smoker, n (%)	2	179 (62%)	26 (79%)	0.17 [+]
Pack-years, mean (SD)	29	22.4 (19.7)	23.0 (17.1)	0.88
Workplace Characteristics				
Underground mining tenure, mean (SD)	4	35.8 (9.6)	28.8 (10.8)	**0.001**
Mining tenure, mean (SD)	2	37.1 (8.7)	30.4 (9.8)	**0.0006**
State of underground mining, n (%)				**0.0001** [+]
Pennsylvania		175 (61%)	5 (15%)	
West Virginia		69 (24%)	14 (42%)	
Virginia		17 (6%)	6 (18%)	
Kentucky		6 (2%)	2 (6%)	
Other [*]		20 (7%)	1 (3%)	
Missing		2 (0.6%)	5 (15%)	
Principal Job, n (%)	0			0.53
Designated high risk		163 (56%)	22 (67%)	
Not designated high risk		68 (24%)	6 (18%)	
Unknown		58 (20%)	5 (15%)	

[*] Other states include AL, CO, IL, OH, and WY

[+] = Fisher's exact test used

Table 2:

Most common principal jobs vary between historic and contemporary miners

Job Description	Historic n = 289	Contemporary n = 33
Designated Occupations		
Cutting machine operators and helpers	15 (5.2%)	1 (3.0%)
Continuous mining machine operators and helpers	26 (9.0%)	9 (27.3%)
Hand loaders, coal diggers, general miners	67 (23.3%)	2 (6.1%)
Timberman and helpers	4 (1.4%)	0
Roof bolters and helpers	7 (2.4%)	5 (15.2%)
Loading machine operators and helpers duckbill operators	5 (1.7%)	1 (3.0%)
Drillers hand machine conveyor men shot fires blasters slate work helpers	7 (2.4%)	0
Work at face jacksetter	26 (9.0%)	4 (12.1%)
Beltmen	4 (1.4%)	0
Shuttle car operators	2 (0.7%)	0
Non-Designated Occupations		
Motormen and brakemen	32 (11.1%)	1 (3.0%)
Car dumpers shaft and slope attendants	1 (0.4%)	0
Work in underground transportation	2 (0.7%)	0
Bonders trackmen and helpers	2 (0.7%)	0
Electricians and helpers wiremen mechanics general repairmen	8 (2.8%)	2 (6.1%)
Ventilation men brattice men sprinklers and masons	1 (0.4%)	0
Clean up men laborers rail recovery	1 (0.4%)	0
Work underground maintenance	3 (1.0%)	0
Superintendent assistant foremen section bosses grade foremen	14 (4.8%)	3 (9.1%)
Fire bosses mine examiners	2 (0.7%)	0
Dispatchers maintenance foremen	1 (0.4%)	0
Tipple operators crushers screeners	1 (0.4%)	0
Unknown		
Work in underground coal mining	25 (8.6%)	3 (9.1%)
No data on occupational history	33 (11.5%)	2 (6.1%)

Table 3:

Comparison of type of PMF between historic and contemporary miners and by principal job

	Type of PMF			P-value*
	Silica	**Mixed**	**Coal**	
Group				
Historic n=289	44 (15.2%)	119 (41.2%)	126 (43.6%)	**<0.0001**[a,b]
Contemporary n=31	18 (58.1%)	7 (22.6%)	6 (19.4%)	
Principal Job				
DO n = 184	29 (15.8%)	73 (39.7%)	82 (44.6%)	**0.03**
Non-DO n = 73	22 (30.1%)	23 (31.5%)	28 (38.4%)	
Mechanized face work n=51	10 (19.6%)	17 (33.3%)	24 (47.1%)	0.05
Non-mechanized face work n=69	4 (5.8%)	31 (44.9%)	34 (49.3%)	

*Pairwise comparisons that were statistically significant after Bonferroni correction (p<0.008 for six tests) are indicated as follows:

*a=*Silica vs. Coal

*b=*Silica vs. Mixed

*c=*Mixed vs. Coal.

Note: Two contemporary cases that were classified as “other” type of PMF were excluded from this analysis.