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2.0 Executive Summary

There are more than 250,000 actively employed miners in the United States and many more former miners. These workers suffer excess rates of chronic respiratory diseases and other adverse health effects. Coal miners are a unique subset of miners for which several national data sets exist that contain information on miners' health. Among coal workers, rates of respiratory disease declined significantly after 1970, recently this trend reversed including an increase in rapidly progressive pneumoconiosis and progressive massive fibrosis in younger workers. To better understand this reversal, our group linked data from three federal agiences to yeild the most comprehensive set of information available to date on the health and mortality of our nation's current and former coal miners.

We performed an analysis of longitudinal health information from the Coal Workers' Health Surveillance Program (CWHSP), which primarily targets active working miners, and the Federal Black Lung Program (FBLP), which includes most former coal miners with significant mining tenures, to better understand disease risk. These data also allowed us to understand important gaps in miner participation in these programs. Next, by linking data to the National Death Index we have been able to conduct studies of respiratory and cardiovascular mortality among those deceased coal miners who participated in both federal programs.

Analysis of these data revealed some striking findings. First, we learned that 45% of miners filing FBLP claims never participated in regular medical surveillance. There was also geographic variability in participation, for example a much smaller proportion of miners participated in surveillance than applied for benefits in Kentucky, Tennessee and Alabama. This represents a large missed opportunity for screening and secondary prevention.

We analyzed FBLP data from nearly 2000 former coal miners and found that 3.7% of those with no evidence of PMF at the time of their initial claim developed PMF by the time of their final chest radiograph, with a mean interval between exams of 8.4 years. A similar analysis of serial lung function measurements in this same population showed that FEV_1 declined from normal to below the LLN in 26.9% of subjects. This indicates that disease may progress even after exposure has ceased and highlights the need to monitor former miners for radiographic and physiologic progression after leaving employment.

We found further evidence verifying the dramatic increase in the number of cases of PMF determined by the FBLP between 1970 and 2016. The proportion of federal claimants with severe lung disease has been increasing significantly since 1978 and accelerated more steeply after 1996. This is particularly concerning since miners filing more recent claims for Federal Black Lung Program benefits are more likely to have worked when modern coal mine dust exposure limits were in effect.

We received cause-of-death data for 34,771 miners who participated in both the FBLP and CWHSP programs. Proportional mortality from non-malignant respiratory disease (NMRD), specifically the pneumoconioses, increased across birth cohorts, with the highest proportions observed in miners born after 1940. This increase is pronounced among younger miners and may reflect increased mortality from progressive massive fibrosis, which previous studies have shown is occurring more frequently and in younger U.S. coal miners.

In summary, we demonstrated significant increases in severe respiratory disease and mortality in US coal miners by linking these datasets for the first time. Our findings emphasize the need for further research on and implementation of primary prevention to reduce coal mine dust exposures, and for improved secondary prevention including expanded medical surveillance of active coal miners to identify early stages of disease and decrease risk for progression.

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Problem Statement and Objective

3.1 Problem Statement

There are an estimated 83,000 coal, 71,000 metal/non-metal, and 99,000 stone/sand/gravel miners actively employed in the United States.[1] The number of former miners is more difficult to ascertain but is likely much higher; the United Mine Workers of America (UMWA) health and pension funds provide for more than 77,000 miners, which represent only a portion of former coal mine workers.[2] Miners suffer an excess of chronic respiratory diseases as well as other adverse health effects from their occupational exposures despite modern mining technology, dust control methods, and dust control regulations.[3]

Coal miners are a unique subset of miners for whom several national data sets exist that allow in-depth study of their health, data that has broad applicability to other populations of miners. Occupational exposure to coal mine dust can cause a broad spectrum of respiratory diseases, including interstitial and fibrotic lung disease,[4,5] and chronic obstructive pulmonary disease (COPD),[6] encompassed by the term coal mine dust lung disease (CMDLD).[7] Despite remarkable progress in reducing pneumoconiosis in coal miners after implementation of the Federal Coal Mine Health and Safety Act of 1969 (The Act), recently this trend has reversed.[8] Equally disturbing is the increased incidence of rapidly progressive pneumoconiosis (RPP)[9] and progressive massive fibrosis (PMF) now being seen in relatively young coal miners.[10]

Several federal agencies, including the National Institute for Occupational Safety and Health (NIOSH) and the Department of Labor (DOL) Division of Coal Mine Workers' Compensation (DCMWC) collect data on the demographic characteristics and health of U.S. coal miners. However, no comprehensive surveillance of miners' health exists, as these agencies have different missions, target populations, and data collection goals.

NIOSH administers the Coal Workers' Health Surveillance Program (CWHSP) for active miners. The CWHSP was originally mandated by the Federal Coal Mine Health and Safety Act of 1969 and began operation in 1970. The primary purpose of the CWHSP is secondary prevention of CMDLD.[11] The program is designed to detect early radiographic CWP in active miners and prevent the progression to disabling disease by allowing miners to exercise their right to work in locations and occupations with lower dust exposure.[12] Coal miners are offered a chest radiograph (CXR) and more recently spirometry, at approximately 5-year intervals at no cost to themselves. Participation in the program is voluntary and has fluctuated over the program's 50 years history.[13,14]

DOL operates the Federal Black Lung Program (FBLP) and administers claims filed under the Black Lung Benefits Act of 1969. The Act provides compensation to coal miners who have totally disabling CMDLD arising out of their coal mine employment and to certain miners' survivors. The Act also provides eligible miners with medical services and supplies needed to

treat their CMDLD.[15] Since 1970, the DOL Division of Coal Mine Workers' Compensation has paid over $46 billion in FBLP benefits.[16] Data from the FBLP have only recently been analyzed for public health purposes,[17] and have never before been linked to other data sets.

The National Death Index (NDI) houses cause of death data for all deceased individuals in the U.S. and has the potential to yield important information about the mortality patterns among coal mine workers. The objective of this study was to combine data from these three federal programs into a data set would represent the most comprehensive set of information available to date on the health and mortality of our nation's current and former coal miners.

3.2 Objective and Specific Aims

Our main research objective was to combine three large, and previously unlinked, data sets to develop an in-depth understanding of the risk factors for cardiopulmonary diseases in U.S. miners, including insight into recent trends in rapidly progressive and advanced cases of pneumoconiosis, with the ultimate goal of developing better targeted prevention strategies. The objectives of this work aligned with those of the solicitation focus area 4.5, "Injury and Disease Exposure and Risk Factors – Surveillance and Epidemiology Methods". This work had several objectives that were relevant to both the "lung function, biomarkers or other early warning signs of health effects" and "the prevalence and incidence of adverse health outcomes among miners" priorities within this focus area.

Our main objective was supported by three specific aims: (1) link the CWHSP, FBLP, and NDI data sets; (2) analyze longitudinal respiratory health information on miners; and (3) conduct mortality studies, using the linked NDI data, of those deceased coal miners who participated in either the CWHSP or FBLP.

3.2.1 Specific Aim 1: Link CWHSP, FBLP, and NDI data sets

Our first aim was to create a single database housing longitudinal health information collected from miners while they were actively mining, after their mining career ended and they entered into the black lung compensation process, and causes of death records. This integrated data set would enable an improved understanding of the spectrum and characteristics of CMDLD as well as potential risks associated with CMDLD. Using these data, we can identify populations who are not participating in the CWHSP while working but who apply for black lung benefits, as well as populations who may be eligible for benefits but have not applied. Based on the gaps identified, we will develop recommendations for both NIOSH and DOL to improve their respective programs' outreach efforts.

3.2.2 Specific Aim 2: Analyze longitudinal cardiopulmonary health information on miners

Using the combined data, we aimed to analyze chest imaging and lung function data during employment, and health information on the same miners who have entered the compensation process following employment. We characterized the progression of disease across the sub-population of miners who have multiple observations derived from the CWHSP and FBLP data sets, comparing measurements taken while employed with those obtained after exposures have ceased. The outcome of this aim will be an improved understanding of the progression of CMDLD, particularly after cessation of coal mine dust exposure. Characterizing risk factors associated with rapid progression and severity of cardiopulmonary diseases will allow for the design of targeted intervention strategies for these costly and often hidden diseases.

3.2.3 Specific Aim 3: Conduct mortality analyses of deceased miners who participated in the CWHSP or FBLP

This aim allows us to evaluate the burden of cardiovascular and respiratory disease mortality and co-morbidities among U.S. coal miners participating in national surveillance and in the FBLP benefits process. In addition to understanding proportional mortality within this population, we plan to compare this population of miners to the general U.S. population as well as populations of workers in non-mining heavy industry using data from the National Vital Statistics System (NVSS). We will also evaluate the contribution of personal and occupational risk factors for disease-specific mortality rates. The outcome of this aim will be identification of risk factors (such as years worked) associated with all-cause and cause-specific mortality rates in this population which can be targets for intervention strategies to reduce the years of potential life lost in this population.

4.0 Research Approach

We have used a wide variety of epidemiologic approaches to address each of our specific aims. These strategies have included descriptive statistics, bivariate analyses, multivariable regression analyses, and time-trend analyses. The approach for each aim is detailed below.

4.1 Specific Aim 1: To link the CWHSP, FBLP, and NDI data sets

4.1.1 Data acquisition

We obtained data from the DOL, NIOSH, and NDI separately in order to perform the data linkages outlines in specific aim 1. As guest researchers at NIOSH, Drs. Cohen and Almberg had access to all data collected as part of the CWHSP from 1970 – present. A Memorandum of Understanding (MOU) was finalized in February 2016 that enabled the study team to obtain identifiable FBLP data from the DOL that included claims made between January 1, 2000 and December 31, 2013. A subsequent amendment allowed for transfer of data on all FBLP claims from 1970 through 2016. A formal application for mortality data was submitted to the NDI in February 2018. Mortality data, including verification of vital status, for more than 34,771 miners participating in the CWHSP and FBLP was received.

4.1.2 Data management and linkage

We performed an initial linkage of the CWHSP and the FBLP data from 2000 – 2013. Data management prior to this linkage included standardizing key linkage variables in both data sets such as SSN, names, and dates of birth. We included all CWHSP data from 1970 through 2016 to maximize the potential for linking to individuals in the FBLP data (2000–2013), who are likely applying for benefits at the end of their mining careers. We included surveillance data through 2016 as former miners are eligible for participating in the CWHSP.

We linked the FBLP and CWHSP data using SSN, name, and date of birth. Eleven SSNs were excluded as they were associated with multiple names and addresses in the CWHSP. We computed basic demographic and geographic descriptive statistics to characterize this population by age, coal mining tenure, and location. We restricted our analysis of CWHSP participants to those born after 1910 and therefore likely have been alive to apply for benefits after the year 2000, to create a comparable population of miners in each dataset. We evaluated miner characteristics associated with non-participation in either CWHSP or FBLP by analyzing subjects who appeared in only one of the two data sets. We also examined the geographic distribution of miners who appeared in one or both data sets to determine if this played a role in program participation. The results from this linkage were published in a manuscript in the Journal of Occupational and Environmental Medicine in October 2017.[18]

After receiving the additional claim data from the DOL, for years prior to 2000 and after 2013, we performed the same data cleaning and linkage approach for these data as we had for the original data transfer of claims from 2000 – 2013.

We received cause of death data from the NDI on deceased miners participating in the CWHSP and FBLP. These data were linked with the CWHSP and FBLP based on unique identifiers in these data sets including SSN, first and last name, and date of birth.

4.2 Specific Aim 2: Analyze longitudinal cardiopulmonary health information on miners

4.2.1 Progression of radiographic disease and lung function impairment

Our longitudinal analysis focused on progression of PMF, absent further coal mine dust exposure, among miners filing FBLP claims between 2000 and 2013. The development of coal workers' pneumoconiosis (CWP) – including its more severe manifestation, PMF – is strongly associated with cumulative coal mine dust exposure. However, there is little information about the development of PMF after exposure to coal mine dust ceases. Using the DOL FBLP data, we identified and characterized the radiographic development of PMF among former coal miners who had ceased coal mine dust exposure. We compared the International Labor Organization (ILO) classifications of the first and final CXRs associated with a miner's claims, for those miners undergoing two or more FBLP examinations at least 5 years apart. We restricted this analysis to miners with at least 10 years of verified coal mine employment. PMF was defined as one or more parenchymal opacities > 1 cm in long-axis diameter. Since our initial analysis, we have expanded this analysis to include miners with claims made between 2013 and 2016.

We analyzed lung function decline among former U.S. miners using the FBLP data as the CWHSP surveys primarily active, and therefore younger, miners with on-going exposure to coal mine dust. We identified 24,802 FBLP claims with valid pulmonary function tests (PFTs) between 2001 and 2013. We selected miners with at least two spirometry tests at a minimum of two years apart, and who had normal forced expiratory volume in one second (FEV_1) on the first test. This was defined as the measured value greater than the lower limit of normal (LLN) based on NHANES III data for Caucasian males since FBLP data do not include race or sex. We excluded subjects with less than ten years of claimed coal mine employment (CME) in order to ensure a population with a significant likelihood of disease based on this minimal exposure. We also excluded those subjects with greater than 30% increase in FEV_1 or forced vital capacity (FVC) on second test; or greater than 50% decrease in FEV_1 or FVC on second test. We examined the proportion of miners with a ventilatory defect and the severity of impairment at last PFT. Linear regression was used to examine the association between years of CME and decline in percent predicted of FEV_1 ($ppFEV_1$) and FVC (ppFVC) between pulmonary function tests, controlling for age at first spirometry and years between tests.

The pattern of ventilatory defect at last testing was defined as:

- Obstruction: $FEV_1/FVC < LLN$ and $FVC > LLN$
- Mixed: $FEV_1/FVC < LLN$ and $FVC < LLN$
- Restriction: $FEV_1/FVC > LLN$ and $FVC < LLN$

Severity of pulmonary impairment at last testing was defined using modified ATS criteria[19] as:

- Mild: $ppFEV_1 > 70\%$ and $FEV_1 < LLN$
- Moderate: $ppFEV_1$ 60-69%
- Moderate-Severe/Severe: $ppFEV_1 < 60\%$

4.2.2 Time-trend analysis of progressive massive fibrosis among U.S. coal miners

Mounting surveillance evidence from the CWHSP shows a marked increase in the prevalence of PMF among active coal miners, supported by evidence from individual black lung clinics,[20] but the national trend in PMF prevalence among former coal miners had not been investigated. Using FBLP data from the DOL, we characterized trends in PMF occurrence among former U.S. coal miners since the program's inception in 1970.

We examined the proportion of miners with between 5 and 60 years of coal mine employment filing black lung benefits claims who received a determination of PMF between 1970 and 2016, by tenure, age, and state of last mine employment. We defined a case of PMF as a miner receiving a determination of PMF by the DOL based on medical evidence.

To better understand how the proportion of claimants with PMF has changed over time, we conducted a time-trend analysis of PMF cases from 1970 to 2016 using logistic regression models to test linear and quadratic trends in the odds of PMF over time while controlling for years of coal mine employment. We calculated the annual proportion and standard error of claimants with PMF for each year in the data and used the National Cancer Institute software Joinpoint to identify significant ($p < .05$) changes in trend. Linear regression analysis was used to test for trend over time in the proportion of claimants with PMF by state. We calculated the annual percent change (APC) in proportion of Federal Black Lung Program claimants with PMF using Joinpoint and linear regression results.

4.3 Specific Aim 3: Conduct mortality studies, using the linked NDI data, of those deceased coal miners who participated in either CWHSP or FBLP

4.3.1 Data source and acquisition

Established by the National Center for health Statistics, the National Death Index (NDI) is a national database of vital status and cause of death data on deaths of U.S. citizens as well as

citizens from U.S. territories. This database is compiled from data collected by state vital statistics offices and is made available for research for a fee.

We applied to the NDI for cause of death data on miners appearing in the CWHSP and FBLP in February 2018. We provided the NDI with a dataset containing the SSNs, names, and dates of birth for the individuals of interest in this study and received year of death, cause of death, and state of residence at time of death from the NDI for those individuals who are deceased. The NDI uses probabilistic linkage methods to identify those death records for a given individual. As a result, the NDI may return multiple possible matches to individual subjects from our submitted dataset. Considerable effort was made to identify true matches for the individuals in the original FBLP and CWHSP datasets from the results returned by the NDI. Miners for whom a true match was identified were linked with the larger FBLP and CWHSP datasets using the unique identifiers of SSN, name, and date of birth.

4.3.2 Statistical analysis

We conducted a series of mortality analyses on those miners who are deceased in this population. The subset of miners with the most health and exposure data are those who participated in the CWHSP and later filed for FBLP benefits (n=34,771). The initial analysis that we performed was a proportional mortality study of this subset, examining the proportion of miners who died from selected causes: non-malignant respiratory disease (NMRD), lung cancer, stomach cancer, and ischemic heart disease (IHD). Within the larger category of NMRD, we examined the proportion of miners who died from coal workers' pneumoconiosis (CWP), all pneumoconioses (excluding asbestosis), and COPD. The ICD-9 and ICD-10 codes for each of these causes are detailed in Table 1. Deaths occurring from 1979–1998 were coded using ICD-9 codes and deaths occurring in 1999 and after were coded using the ICD-10 codes.

Proportional mortality is defined as the proportion of deaths within a specific population and time period attributable to specific causes of death. Proportional mortality is not a mortality rate and can therefore not inform risk of death from a specific cause in this population. Instead, it can inform us as to the leading causes of death within a population at a specific time point. Increases in proportional mortality may reflect an actual increase in mortality from a specific cause, but may also be caused by decreases in mortality from other important causes.

Table 1. ICD-9 and ICD-10 codes used for classifying selected causes of death in the NDI data of U.S. coal miners.

Cause of death	ICD-9 Codes	ICD-10 Codes
Non-malignant respiratory disease	460 – 519	J00 – J99
Pneumoconioses (excluding asbestosis)	500, 502, 503, 505	J60 – J62, J64

Coal workers' pneumoconiosis	500	J60
Chronic obstructive pulmonary disease	490 – 492	J43, J44
Ischemic heart disease	410 – 414	I20 – I25
Lung cancer	162	C34
Stomach cancer	151	C16

We examined proportional mortality in association with birth cohort, age, coal mine employment (years), and geographic region of last coal mine employment. In addition to examining the underlying, or most proximate, cause of death, we also examined the proportional mortality from these selected causes if they were listed as an underlying or contributing cause of death on the death certificate. We examined differences in proportional mortality from these causes as they relate to whether or not the miner was determined to have PMF. All analyses were performed using SAS version 9.4 (Cary, NC).

5.0 Summary of Accomplishments

5.1 Specific Aim 1: To link the CWHSP, FBLP, and NDI data sets

5.1.1 CWHSP and FBLP linkage

There were 48,841 claims in the FBLP database from 2000 through 2013, representing 37,548 unique miners. Most claims were filed by a living miner (n = 31,576; 84%), the remainder by a surviving family member. Mean age and verified mining tenure of FBLP living miner claimants was 61.6 (SD 10.0) and 19.4 (SD 9.8) years, respectively. The median number of CXRs submitted to the FBLP by miners was one.

Between 1970 and 2016, 273,644 miners participated in the CWHSP. The mean age of miners at the time of their first or only encounter with the CWHSP was 33.3 (SD 12.3) and was 41.2 (SD 12.5) at the time of their last encounter with the CWHSP. The median self-reported coal mining tenure of miners in the CWHSP was 4.0 years. Twenty-eight percent of miners in the CWHSP participated to obtain a pre-employment CXR. These miners appear in the CWHSP dataset with no reported coal mine tenure and only one CXR.

A total of 22,903 miners participated in both programs (Figure 1). Thirty-nine percent of miners filing FBLP claims never participated in the CWHSP. An additional 6.5% of claimants only participated for their initial employment screening. A higher proportion of miners appearing in both programs were non-Hispanic white (84%) and male (89%) compared to those appearing in the CWHSP only (71% non-Hispanic white and 84% male). However, a large proportion (14%) of miners participating in only the CWHSP were missing data on gender, and the FBLP does not collect gender information. Miners appearing in both programs participated in the CWHSP surveillance more often than those participating in the CWHSP alone (Table 2).

Miners participated in the CWHSP across 25 states during the time period 1970 through 2016, while the FBLP received claims from miners working in 38 states from between 2000 through 2013. Sixty percent of miners were working in the states of West Virginia (26%), Kentucky (19%), and Pennsylvania (15%) at the time of their last or only CWHSP encounter. The majority of miners applying for FBLP benefits last worked in Kentucky (36%), West Virginia (26%), and Virginia (9%). Of those miners that appeared in both programs, 73% last worked in Kentucky, West Virginia, and Virginia (Table 3). A majority (88%) of miners worked in the same state at the time of filing their FBLP claim as they were working at the time of their last CWHSP encounter.

These findings were presented at the American Thoracic Society International Conference in Washington, D.C. in May 2017 and published in the Journal of Occupational and Environmental Medicine in October 2017.[18]

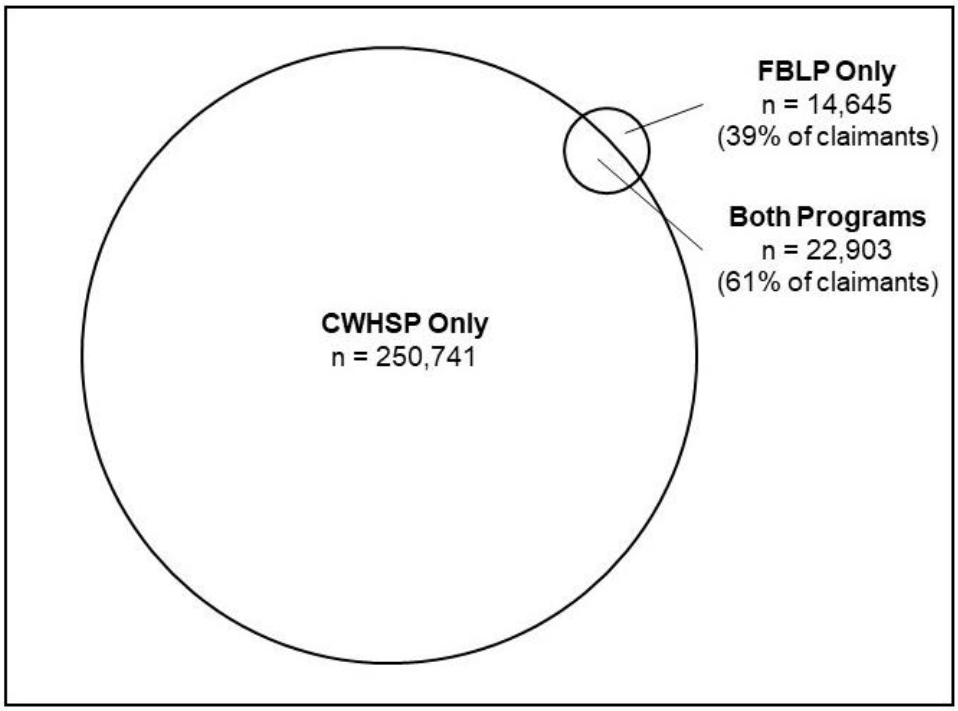

Figure 1. Venn diagram of the overlap between participants in the NIOSH Coal Workers' Health Surveillance Program (CWHSP) (N = 273,644) and the Department of Labor's Black Lung Benefits Program (FBLP) (N = 37,548), 1970 – 2013.

This unique study linking two sources of coal miners' health data has provided some insights into the strengths and weaknesses of these two programs. The combined data facilitate investigations into factors associated with participation and non-participation in either or both programs. Miners who participate in the CWHSP tend to participate only once (n=153,262; 61.1%), and at a relatively young age (mean age of first or only encounter between 31 and 35 years), with many of these cases participating as part of a pre-employment CXR. For those that appear more than once in the CWHSP, the difference in median age between the first and last encounter is 13 years (age 28 and age 41), somewhat longer than the median duration of coal mine employment of 10 years. The mean age of miners applying for FBLP benefits was 59 years. A large proportion (39%) of miners applying for FBLP benefits had never participated in the CWHSP while actively mining, demonstrating missed opportunities for secondary prevention.

The geographic distribution of participation in the two programs is also revealing. Two thirds of miners who participated in both programs were from Kentucky and West Virginia. While the proportion of miners participating in each program in West Virginia was comparable between

the two programs, the proportion participating in the CWHSP in Kentucky was only half that of the FBLP. Similarly low proportions were found in Tennessee and Alabama. These differences could reflect many factors that were not measurable in this study. For example, more miners from these states may become ill enough to consider applying for FBLP; there may be a difference in awareness of the FBLP; differences in state compensation benefits may play a role; or miners may believe that there are disadvantages for participation in surveillance that vary by state.[20] Further study of these and other possible factors is important given that the central Appalachian coal fields have been identified as an area with significant rates of rapidly progressive and advanced disease.[21–25]

The linkage of these data sets indicates that the current CWHSP captures relatively young coal miners with relatively short mining tenures. Comparing the two datasets suggests that increased surveillance efforts are needed throughout a miners' career to capture early disease among older, more experienced miners, with a focus on Central Appalachia. Our findings also show the importance of establishing a national surveillance program that tracks miners after their employment ceases and into retirement.

Table 2. Distribution of demographic and surveillance encounter characteristics among U.S. coal miners appearing in the CWHSP or FBLP only compared to those that appear in both programs, 1970 − 2013. The CWHSP data is restricted to those born after Jan 1, 1910 (n = 273,644).

Variable	CWHSP and FBLP	CWHSP Only	FBLP Only
Total N	22,903	250,741	14,645
Initial employment only N (%)	2,431 (10.6)	72,880 (29.1)	-
Race *N (%)*			
Non-Hispanic White	19,285 (84.2)	178,999 (71.4)	-
Non-Hispanic Black	877 (3.8)	4,741 (1.9)	-
Other	173 (0.8)	2,578 (1.0)	-
Missing	2,568 (11.2)	64 423 (25.7)	-
Sex *N (%)*			
Male	20,457 (89.3)	210,326 (83.9)	-
Female	232 (1.0)	6,430 (2.6)	-
Missing	2,214 (9.7)	33,985 (13.6)	-
Age at Only Encounter[a]			
Mean (Median)	35.3 (34)	34.6 (31)	-
Range	16−89	15−92	-
Missing N (%)	0 (0.0)	18 (0.01)	-
Age at First Encounter[b]			
Mean (Median)	30.1 (28)	31.5 (28)	60.2 (60)
Range	17−72	15−75	24−102
Missing N (%)	1 (0.0)	0 (0.0)	5 (0.07)
Age at Last Encounter[c]			
Mean (Median)	42.5 (43)	41.0 (41)	68.2 (69)
Range	17−91	17−88	29−100
Missing N (%)	0 (0.0)	0 (0.0)	1 (0.02)
Number of CXRs			
Mean (Median)	2.3 (2)	1.7 (1)	1.2 (1)
Range	1−14	1−28	1 - 7
Coal Mine Employment[d]			
Mean (Median)	14.0 (12)	13.7 (10)	16.0 (10.4)
Range	0−60	0−89	0 - 50
Missing N (%)	0	0	283 (1.9)

[a] Among CWHSP, age at radiograph for miners participating only once in the program (CWHSP and FBLP n = 8,784; CWHSP Only n = 153,262).

[b] Age at first CWHSP radiograph for miners appearing in both datasets (n = 14,118) or the CWHSP Only (n = 97,479). Age at first CWHSP encounter based only on those miners with more than one CWHSP chest radiograph. Age at first or only FBLP claim ("FBLP Only") is based on living miners only (n = 7,558).

[c] Age at last CWHSP radiograph for miners appearing in both datasets (n = 14,118) or the CWHSP Only (n = 97,479). Age at last CWHSP encounter based only on those miners with more than one CWHSP chest radiograph. Age at last FBLP claim ("FBLP Only") is based on living miners only (n = 5,784).

[d] Coal mining employment (in years) calculations exclude Initial Employment participants in the "CWHSP Only" and "CWHSP and FBLP" groups, as they have 0 years of coal mine employment at time of participation in the CWHSP. Among "FBLP Only" claimants, verified coal mine employment at last or only FBLP claim.
"–" Indicates where data is not available from a given program.

Table 3. State in which coal miners appearing in the CWHSP and FBLP programs worked at time of their last surveillance chest radiograph or at the time of their first FBLP claim.

	CWHSP		**FBLP**		**Both**	
State	**N**	**(%)**	**N**	**(%)**	**N**	**(%)**
West Virginia	72,294	(26.4)	9,737	(25.9)	6,532	(28.5)
Kentucky	50,518	(18.5)	13,366	(35.6)	7,910	(34.5)
Pennsylvania	41,075	(15.0)	2,159	(5.7)	1,282	(5.6)
Illinois	22,462	(8.2)	1,889	(5.0)	1,386	(6.1)
Virginia	21,134	(7.7)	3,374	(9.0)	2,185	(9.5)
Ohio	12,360	(4.5)	1,302	(3.5)	692	(3.0)
Colorado	11,758	(4.3)	165	(0.4)	125	(0.5)
Alabama	10,173	(3.7)	2,563	(6.8)	1,565	(6.8)
Utah	9,731	(3.6)	295	(0.8)	254	(1.1)
Indiana	5,452	(2.0)	439	(1.2)	118	(0.5)
Wyoming	3,103	(1.1)	129	(0.3)	21	(0.1)
Texas	2,331	(0.9)	*		0	(0.0)
Tennessee	1,761	(0.6)	1,041	(2.8)	245	(1.1)
New Mexico	1,640	(0.6)	107	(0.3)	32	(0.1)
Montana	825	(0.3)	32	(0.1)	*	
Arizona	606	(0.2)	93	(0.2)	44	(0.2)
Maryland	511	(0.2)	39	(0.1)	12	(0.1)
North Dakota	434	(0.2)	*		0	(0.0)
Other	678	(0.2)	225	(0.6)	*	
Missing	4,798	(1.8)	583	(1.6)	493	(2.2)
Total	**273,644**		**37,548**		**22,903**	

[a] "Other" category includes Alaska, Arkansas, California, District of Columbia, Florida, Georgia, Idaho, Iowa, Kansas, Louisiana, Massachusetts, Michigan, Mississippi, Missouri, New Jersey, New York, North Carolina, Oklahoma, South Carolina, Vermont, Washington. Data was aggregated due to low cell counts.
* Frequencies <10 are suppressed.

5.1.2 Linkage of NDI results

To enhance the linked dataset of miners participating in both the CWHSP and FBLP, we requested and obtained cause of death data on all deceased miners participating in both programs. We were able to link the cause of death data for 34,771 miners participating in each program who died between 1979 and 2017, representing 97.3% of all miners in this subpopulation. Prior to submitting the list of individuals to the NDI for mortality data, all SSNs, names, and dates of birth were standardized, allowing for complete reverse-linkage to the CWHSP and FBLP linked dataset. As described in section 4.3.2, ICD-9 and ICD-10 codes were used to classify both the underlying cause of death and all contributing causes of death, for which there are up to 20 listed per individual.

5.2 Specific Aim 2: Analyze longitudinal cardiopulmonary health information on miners

5.2.1 Radiographic progression absent further exposure

Using the DOL FBLP data, we identified and characterized the radiographic development of PMF among former coal miners across multiple FBLP claims, a population with no further coal mine dust exposure contributing to the development and progression of PMF. We found that the mean age of former miners (n=1,938) at the time of their initial CXR was 58.6 (SD 8.4) years, with a mean of 21.8 years of verified coal mine employment (SD 7.1 years). The mean interval between CXRs was 8.1 years (SD 2.06, range 5 – 13 years). Among former miners in the FBLP data, we found that 3.7% of coal miners with no evidence of PMF at the time of initial CXR developed PMF by the time of their final CXR, with a mean interval between CXRs of 8.4 years. This finding highlights the need to monitor former miners for radiographic progression after leaving employment. It is important to note that these findings may not be generalizable to miners with less than 10 years of coal mine employment. We presented these results at the American Thoracic Society International Conference in Washington, D.C. in May 2017. We have subsequently expanded this analysis to include miners with additional FBLP claims from 2013–2016. A manuscript detailing this analysis and results is in preparation, and we anticipate submission to a peer-reviewed journal in the spring of 2019.

5.2.2 Progression of lung function impairment absent further exposure

Results from our analysis of lung function decline among former U.S. coal miners absent further exposure were shared at the 2018 American Thoracic Society annual meeting. We identified 2,689 miners with spirometry data that met our inclusion criteria. Age at the time of first PFT ranged from 34 to 88 years (median = 59). Years of claimed CME ranged from 10 to 62 (median = 25). The time between PFTs ranged from 2 to 13 years (median = 5). The mean (±SE) decline in ppFEV$_1$ was 6.49% (± 0.26%, $p<0.0001$) and decline in ppFVC was 6.14% (± 0.26%, $p<0.0001$). On second testing, FEV$_1$ declined from normal to below the LLN in 26.9% of

subjects. Linear regression demonstrated a non-significant association of ppFEV$_1$ loss and years of CME of 0.06% (± 0.03%, p=0.1).

We found that over one-fourth of former coal miners with normal lung function at the time of their first FBLP claim had accelerated lung function decline absent further exposure. This decline was associated with years of CME (p=0.1). While analysis was limited by the lack of demographic and smoking data, this finding supports the need to monitor for lung function abnormalities after miners leave employment. It is important to note that these findings may not be generalizable to miners with less than 10 years of coal mine employment. A manuscript of these findings is in preparation and will be submitted for publication in the spring of 2019.

5.2.3 Increase in progressive massive fibrosis 1970 – 2016

We identified 4,679 PMF cases determined by the DOL between 1970 and 2016. Notably, 50% of these cases (2,318) were identified since 2000. We found that the proportion of PMF cases among Federal Black Lung Program claimants has been increasing significantly since 1978, accelerating more steeply since 1996 (Figure 2). DOL data show that 2,474 miners were determined to have PMF from 1996 to 2016, exceeding the total number of cases in the previous 26 years. This is particularly notable because miners filing more recent claims for Federal Black Lung Program benefits are more likely to have worked when respirable coal mine dust limits were in effect. Nationally, the percentage of miners with a determination of PMF among those applying for Federal Black Lung Program benefits increased from 0% in 1972 to 8.3% in 2014. Most miners with PMF last worked in West Virginia (28.4%), Kentucky (20.2%), Pennsylvania (20.0%), or Virginia (15.3%). States with the greatest increase in percentage of PMF determinations were Kentucky (0% in 1972, 9% in 2014), Tennessee (0% in 1970, 10% in 2016), West Virginia (0% in 1972, 11% 2016), and Virginia, where in 2015, 12% of claimants had a determination of PMF (Figure 3). The percentage of PMF for the rest of the U.S. remained under 4%.

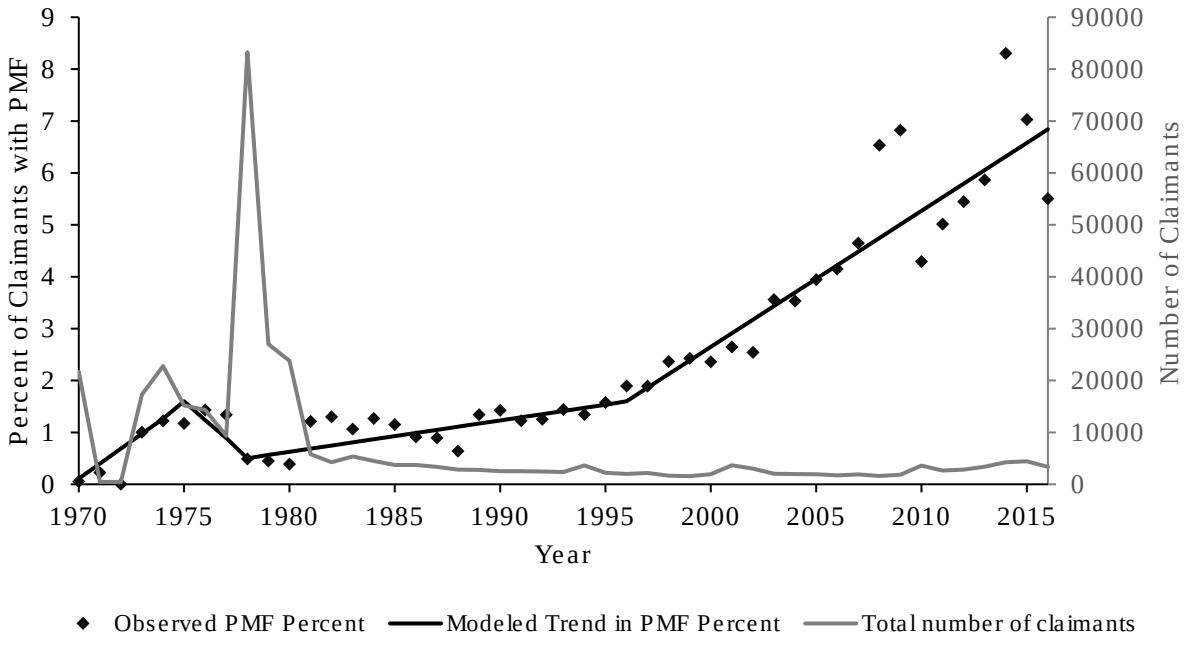

Figure 2. Number of claimants for Federal Black Lung Program benefits and the percentage of these claimants that received a determination of PMF during their claim process, 1970–2016. Observed PMF percent was calculated by dividing the number of claimants with a determination of PMF by the total number of new claimants in that year. Observed and Joinpoint regression model results are displayed. Data restricted to those miners with between 5 and 60 years of coal mine employment. Data source: U.S. Department of Labor, Office of Workers' Compensation Programs, Division of Coal Mine Workers' Compensation.

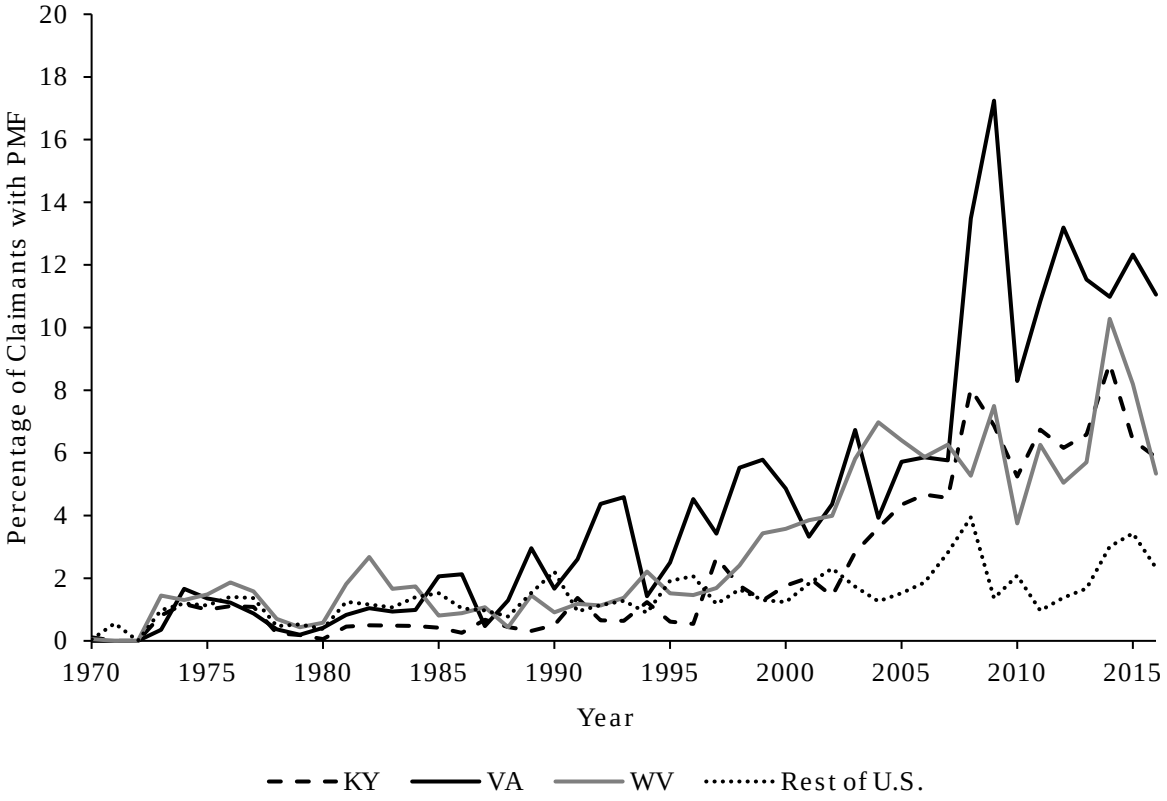

Figure 3. Percent of claimants Federal Black Lung Program benefits that received a determination of PMF during their claim process in the central Appalachian states of Kentucky, Virginia, and West Virginia compared to the rest of the U.S., 1970–2016. Data restricted to those miners with between 5 and 60 years of coal mine employment. Data source: U.S. Department of Labor, Office of Workers' Compensation Programs, Division of Coal Mine Workers' Compensation.

This analysis provides evidence of a substantial increase in the number and proportion of former miners with PMF following the passage of modern dust controls in 1970. For the most recent period of available data (1996–2016), the number of miners with PMF (n=2,474) is more than ten times greater than the number identified in working miners screened by the CWHSP (n=225). Our findings are also consistent with active-miner surveillance reports[21] indicating that highest rates of PMF are in the central Appalachian states of Virginia, West Virginia, and Kentucky, as well as identifying a previously unrecognized increase in percentage of PMF claims from Tennessee. The substantial increase in cases of this disabling but preventable disease points to the need for focused research on and implementation of primary prevention to reduce coal mine dust exposures, and for improved secondary prevention including expanded medical surveillance of active coal miners to identify early stages of disease and decrease risk for progression. We presented this work at the American Thoracic Society in San Diego, CA on May 22, 2018. A

manuscript detailing these findings was published in the Annals of the American Thoracic Society in August 2018.[26]

5.3 Specific Aim 3: Conduct mortality studies, using the linked NDI data, of those deceased coal miners who participated in either CWHSP or FBLP

We received cause-of-death data from the NDI for 34,771 (97.3%) of the 35,743 miners who participated in both the FBLP and CWHSP programs. This mortality data was linked to the CWHSP and FBLP data using SSN, name, and date of birth.

5.3.1 Descriptive statistics

The study population included 34,771 deceased miners who had previously applied for federal benefits between 1970 and 2016 and had participated in the CWHSP. Average age and coal mine employment at time of death was 72 years and 26 years, respectively. Forty percent of the 34,771 miners in this population were missing data on race and sex. Of those with information on race and sex, 96% were non-Hispanic white and over 99% were male. The percentage of deaths in this population increased across age groups and decreased across birth cohorts (Table 4). Non-malignant respiratory disease (NMRD) accounted for 20% of the underlying causes of death in this population, and was an underlying or contributing cause of death for 51.3% of miners in this population. Lung cancer accounted for 11.3% of these deaths and ischemic heart disease (IHD) for 23.3%. Nearly 61% of the deceased miners in this population last worked in the central Appalachian states of Kentucky (18.4%), Virginia (10.1%), and West Virginia (32.4%).

The proportional mortality from the selected causes of death have changed over time for miners filing for federal benefits between 1970 and 2016 (Figure 4). Deaths from an underlying cause of NMRD have increased while deaths from IHD have decreased. The increase in deaths from NMRD are being driven by the increase in COPD deaths.

5.3.2 Proportional mortality across birth cohorts

We examined the change in proportional mortality from selected causes by birth cohort, while controlling for the age of the miner at death. Proportional mortality from NMRD increased significantly ($p<0.05$) among miners aged 65–74 born after 1930 (1930–1939, 28%; 1940–1970, 32%) compared to those born before 1930 (Table 5); a trend was observed among deaths from COPD as well. Proportional mortality from NMRD, specifically pneumoconioses, among younger miners (<65 years) increased significantly in the most recent birth cohort compared to earlier birth cohorts. Proportional mortality from lung cancer was significantly elevated among older miners (19%) in the most recent birth cohort (from 1940 onward) compared to miners of the same age in previous cohorts (7–11%). Proportional mortality from IHD decreased significantly over successive birth cohorts. We observed no difference in proportional mortality from stomach cancer over birth cohort and age group in this population.

In an effort to control for secular changes in mortality, we analyzed the proportional mortality from each selected cause of death by region and birth cohort. Proportional mortality from NMRD increased significantly in the central Appalachian states of Kentucky, Virginia, and West Virginia across birth cohorts, while no differences were observed across cohorts in the eastern, interior, or western regions of the U.S.

Table 4. Descriptive characteristics of deceased miners (N = 34,771) applying for Federal Black Lung Program benefits between 1970 – 2016.

Variable	n	%
Age at Death		
<65	8,152	23.4
65–74	10,949	31.5
≥75	15,670	45.1
Birth Cohort		
<1920	14,737	42.4
1920–1929	10,910	31.4
1930–1939	4,887	14.1
≥1940	4,237	12.2
Underlying Cause of Death[a]		
NMRD	7,063	20.3
CWP	2,360	
All pneumoconiosis	2,894	
COPD	2,689	
Lung Cancer	3,920	11.3
Stomach Cancer	255	0.7
IHD	8,094	23.3
Contributing Causes of Death[b]		
NMRD	17,850	51.3
CWP	6,705	
All pneumoconiosis	8,158	
COPD	9,021	
Lung Cancer	4,355	12.5
Stomach Cancer	288	0.8
IHD	11,600	33.4
Region Last Worked[c]		
Kentucky	6,402	18.4
Virginia	3,525	10.1
West Virginia	11,259	32.4
Eastern	10,562	30.4
Interior	2,064	5.9
Western	959	2.8
Coal Mine Employment (years)		
<10	1,877	5.4
10 – 19	7,589	21.8

20 – 29	9,320	26.8
≥30	12,732	36.6
Missing	3,253	9.4

[a] Non-malignant respiratory disease (NMRD) category contains coal workers' pneumoconiosis (CWP), all pneumoconioses excluding asbestosis, and chronic obstructive pulmonary disease (COPD).
[b] Categories are based on underlying and contributing causes of death and are not exclusive.
[c] Eastern region includes the states of AL, CT, DC, DE, FL, GA, MA, MD, ME, NC, NH, NJ, NY, OH, TN, RI, SC, and VT. Interior region includes the states of AR, IA, IL, IN, KS, LA, MI, MN, MO, MS, ND, NE, OK, SD, TX, and WI. Western region includes the states of AK, AZ, CA, CO, HI, ID, MT, NM, NV, OR, UT, WA, and WY.

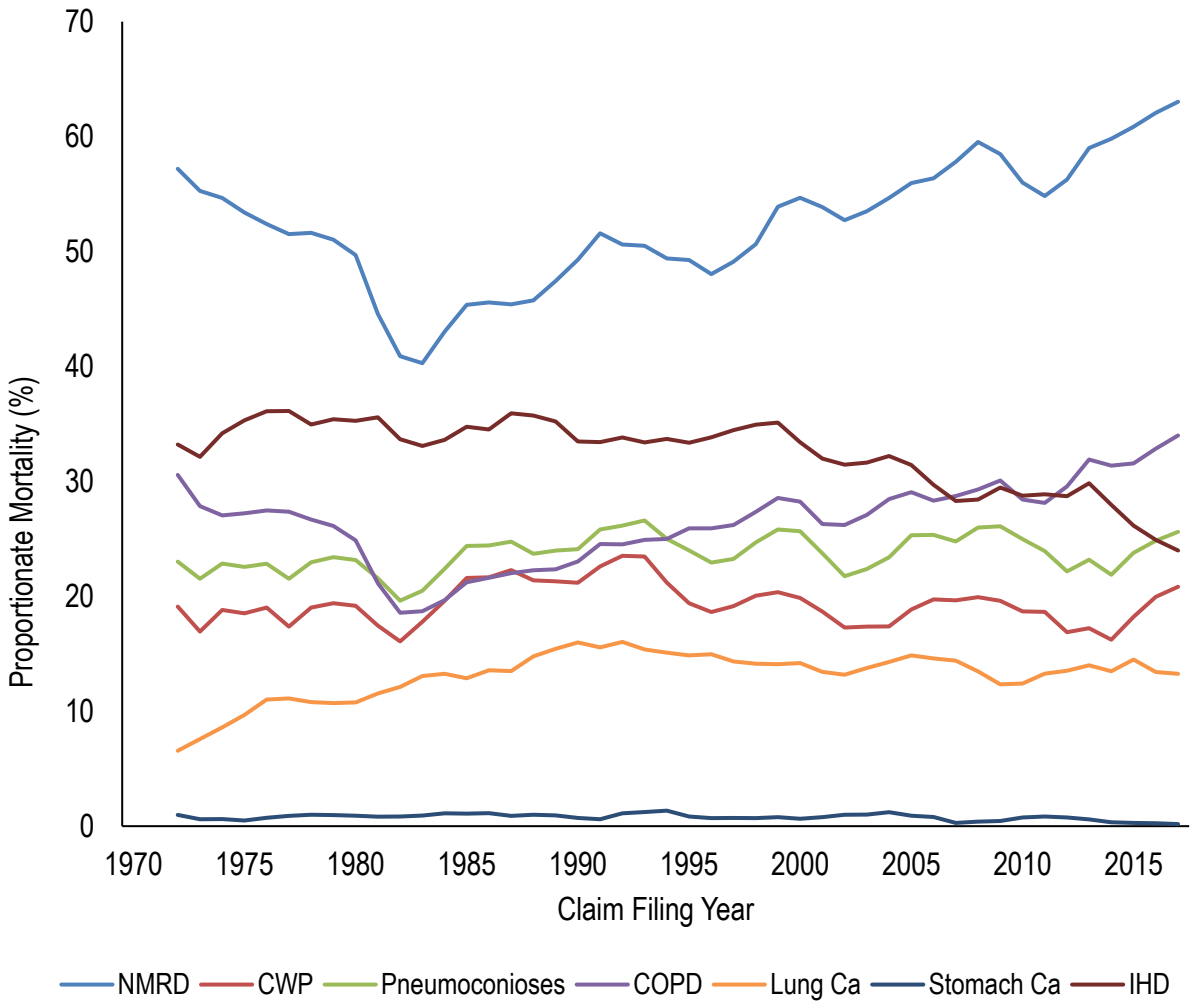

Figure 4. Change in proportional mortality from selected causes among U.S. coal miners who participated in the Coal Workers' Health Surveillance Program and the Federal Black Lung Program 1970 – 2016. Proportional mortality is plotted against the year in which the miner first applied for FBLP benefits.

Table 5. Distribution of and proportional mortality from selected causes of death among 34,771 deceased U.S. coal miners applying for Federal Black Lung Program benefits, 1970 – 2016.

		NMRD[a]		Pneumoconioses[b]		COPD[c]		Lung Cancer[d]		IHD[e]	
Birth Cohort	**N**	**N**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1889 – 1919	14,737										
<65	586	59	10.1	28	4.8	24	4.1	76	13.0	198	33.8
65 – 74	4,604	691	15.0	302	6.6	307	6.7	544	11.8	1,392	30.2
≥75	9,547	2,065	21.6	800	8.4	808	8.5	648	6.8	2,272	23.8
1920 – 1929	10,910										
<65	2,581	299	11.6	118	4.6	141	5.5	366	14.2	793	30.7
65 – 74	3,533	653	18.5	295	8.3	293	8.3	576	16.3	852	24.1
≥75	4,796	1,294	27.0	522	10.9	549	11.4	395	8.2	903	18.8
1930 – 1939	4,887										
<65	1,995	222	11.1	75	3.8	120	6.0	326	16.3	538	27.0
65 – 74	1,623	460	**28.3**	210	**12.9**	194	**12.0**	278	17.1	281	**17.3**
≥75	1,269	425	**33.5**	171	**13.5**	190	**15.0**	145	11.4	170	**13.4**
1940 – 1970	4,237										
<65	2,990	501	**16.8**	214	**7.2**	184	6.2	383	12.8	542	**18.1**
65 – 74	1,189	375	**31.5**	150	12.6	159	**13.4**	172	14.5	145	**12.2**
≥75	58	19	32.8	*		*		11	**19.0**	*	

* Frequencies <10 are suppressed.

[a] Non-malignant respiratory disease (ICD-9 codes 460–519; ICD-10 codes J00-J99)

[b] Includes coal workers' pneumoconiosis, silicosis, and pneumoconiosis resulting from exposure to inorganic dusts; excludes asbestosis (ICD-9 codes 500, 502, 503, 505; ICD-10 codes J60–J62, J64)

[c] Chronic obstructive pulmonary disease, including emphysema (ICD-9 codes 490–492; ICD-10 codes J43, J44.0, J44.1, J44.8, J44.9)

[d] Lung cancer includes ICD-9 code 162; ICD-10 code C34

[e] Ischemic heart disease includes ICD-9 code 410–414; ICD-10 codes I20 – I25

Bold indicates significantly different ($p < .05$) from the proportional mortality observed in the age groups in birth cohort 1889 – 1919, as indicated through logistic regression and Chi-square tests.

Table 6. Distribution of and proportional mortality from selected causes of death among 34,771 deceased U.S. coal miners applying for Federal Black Lung Program benefits, 1970 –2016, by birth cohort and region of last coal mine employment.

		NMRD[a]		Pneumoconioses		COPD[c]		IHD[d]		Lung Cancer		Stomach Cancer	
Birth Cohort	**N**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
1889 – 1919	14,737												
Eastern	6332	1,216	19.2	587	9.3	358	**5.7**	1708	**27.0**	467	**7.4**	60	0.9
Interior	1,260	214	17.0	61	4.8	107	8.5	311	24.7	142	**11.3**	*	0.3
Western	583	142	24.4	57	9.8	47	8.1	107	18.4	32	**5.5**	*	0.9
Central Appalachia	6,562	1,243	**18.9**	425	6.5	520	7.9	1,736	**26.5**	627	**9.6**	47	0.7
1920 – 1929	10,910												
Eastern	2917	548	18.8	262	9.0	196	**6.7**	698	**23.9**	315	**10.8**	28	1.0
Interior	477	88	18.4	29	6.1	36	7.5	117	24.5	75	**15.7**	*	0.2
Western	251	61	24.3	27	10.8	18	7.2	44	17.5	13	**5.2**	*	1.6
Central Appalachia	7,265	1,549	**21.3**	617	8.5	622	8.6	1,689	**23.2**	934	**12.9**	49	0.7
1930 – 1939	4,887												
Eastern	762	150	19.7	61	8.0	60	**7.9**	157	**20.6**	119	**15.6**	*	0.5
Interior	215	43	20.0	15	7.0	22	10.2	47	21.9	42	**19.5**	*	0.9
Western	71	27	38.0	11	15.5	*	11.3	*	9.9	11	**15.5**	*	0.0
Central Appalachia	3,839	887	**23.1**	369	9.6	373	9.7	778	**20.3**	577	**15.0**	27	0.7
1940 – 1970	4,237												
Eastern	551	101	18.3	38	6.9	35	**6.4**	95	**17.2**	79	**14.3**	*	1.5
Interior	112	21	18.8	*	2.7	11	9.8	20	17.9	17	**15.2**	*	1.8
Western	54	13	24.1	*	3.7	*	14.8	*	11.1	*	**1.9**	*	1.9
Central Appalachia	3,520	760	**21.6**	330	9.4	268	7.6	574	**16.3**	469	**13.3**	13	0.4

* Frequencies <10 are suppressed.

Bold indicates significantly different (p <.05) from the proportional mortality observed in the age groups in birth cohort 1889 – 1919, as indicated through logistic regression and Chi-square tests.

[a] Non-malignant respiratory disease (ICD-9 codes 460–519; ICD-10 codes J00-J99)

[b] Includes coal workers' pneumoconiosis, silicosis, and pneumoconiosis resulting from exposure to inorganic dusts; excludes asbestosis (ICD-9 codes 500, 502, 503, 505; ICD-10 codes J60–J62,

[c] Chronic obstructive pulmonary disease, including emphysema (ICD-9 codes 490–492; ICD-10 codes J43, J44)

[d] Lung cancer includes ICD-9 code 162; ICD-10 code C34

[e] Ischemic heart disease includes ICD-9 code 410–414; ICD-10 codes I20 – I25

5.3.3 Proportional mortality by disease severity

One of our aims was to examine differences in mortality between miners with severe disease compared to those without. For this purpose, we compared the proportional mortality between miners with PMF to those without a determination of PMF. There were no significant differences between PMF and non-PMF miners in age at death (Table 7), however we did observe significant differences in proportional mortality across birth cohorts. Among those miners born most recently (≥1940), there was a significantly elevated mortality among PMF miners compared to non-PMF miners.

We examined both the underlying cause of death, as well as any contributing cause (including underlying), among PMF and non-PMF miners and found consistent trends with each classification. Miners with PMF had higher proportional mortality from NMRD including CWP, all pneumoconioses, and COPD than non-PMF miners. Proportional mortality from lung cancer and ischemic heart disease was lower among PMF miners compared to non-PMF miners, possibly reflecting the higher mortality from NMRD in this population of miners with severe disease. Notably, among miners with a determination of PMF, only 41% had pneumoconiosis listed as an underlying or contributing cause of death on their death certificate. PMF miners had increased mortality within the highest coal mine employment tenure categories (20–29, ≥30 years) compared to non-PMF miners.

As in previous analyses, we observed regional differences between PMF and non-PMF miners with regards to mortality patterns. Mortality among PMF miners was higher in the states of Virginia and West Virginia compared to non-PMF miners (Table 7). Attempting to control for secular changes in mortality, we analyzed the proportional mortality from each selected cause of death by region and birth cohort.

Table 7. Descriptive characteristics of deceased miners (N = 34,771) applying for Federal Black Lung Program benefits between 1970 – 2016, by PMF status.

	Non-PMF Miners (n=33,648)		PMF Miners (n=1,123)		
Variable	**n**	**%**	**n**	**%**	**p-value***
Age at Death					
<65	7,878	23.4	274	24.4	0.37
65–74	10,583	31.5	366	32.6	
≥75	15,187	45.1	483	43.0	
Birth Cohort					
<1920	14,504	43.1	233	20.7	<.0001
1920-1929	10,534	31.3	376	33.5	
1930-1939	4,702	14.0	185	16.5	
≥1940	3,908	11.6	329	29.3	
Underlying Cause of Death[a]					
NMRD	6,619	19.7	444	39.5	<.0001
CWP	2,165	6.4	195	17.4	<.0001
Pneumoconioses	2,639	7.8	255	22.7	<.0001
Emphysema	278	0.8	11	1.0	0.58
COPD	2,560	7.6	129	11.5	<.0001
Lung Cancer	3,818	11.3	102	9.1	0.02
Stomach Cancer	248	0.7	7	0.6	0.66
IHD	7,948	23.6	146	13.0	<.0001
Other Causes	15,439	45.9			
Contributing Causes of Death[b]					
NMRD	17,072	50.7	778	69.3	<.0001
CWP	6,360	18.9	345	30.7	<.0001
Pneumoconioses	7,701	22.9	457	40.7	<.0001
Emphysema	962	2.9	33	2.9	0.88
COPD	8,641	25.7	380	33.8	<.0001
Lung Cancer	4,241	12.6	114	10.2	0.01
Stomach Cancer	279	0.8	9	0.8	0.92
IHD	11,319	33.6	281	25.0	<.0001
Region Last Worked[c]					
Kentucky	6,197	18.4	205	18.3	<.0001
Virginia	3,346	9.9	179	15.9	
West Virginia	10,848	32.2	411	36.6	
Eastern	10,277	30.5	285	25.4	
Interior	2,043	6.1	21	1.9	
Western	937	2.8	22	2.0	
Coal Mine Employment (years)					
<10	1,860	6.1	17	1.5	<.0001
10 – 19	7,360	24.2	229	20.7	
20 – 29	8,943	29.4	377	34.0	

≥30	12,247	40.3	485	43.8	

[a] Non-malignant respiratory disease (NMRD) category contains coal workers' pneumoconiosis (CWP), all pneumoconioses excluding asbestosis, and chronic obstructive pulmonary disease (COPD) categories.
[b] These categories are not mutually exclusive. Individuals are categorized based on underlying and contributing causes of death.
[c] Eastern region includes the states of AL, CT, DC, DE, FL, GA, MA, MD, ME, NC, NH, NJ, NY, OH, TN, RI, SC, and VT. Interior region includes the states of AR, IA, IL, IN, KS, LA, MI, MN, MO, MS, ND, NE, OK, SD, TX, and WI. Western region includes the states of AK, AZ, CA, CO, HI, ID, MT, NM, NV, OR, UT, WA, and WY.
* P-value based on results of Chi-square test of proportions

in Conclusions

Proportional mortality from NMRD, and specifically pneumoconioses, increased across birth cohorts, with the highest proportions observed in miners born after 1940. This increase is pronounced among younger miners and may reflect increased mortality from progressive massive fibrosis, which is occurring more frequently and in younger U.S. coal miners. The increased proportional mortality from lung cancer among the oldest age group in the most recent birth cohort may reflect greater exposure to workplace carcinogens (e.g., diesel exhaust, respirable silica) for which further analysis is planned.

This analysis verifies increased mortality among miners with severe disease and among miners who last worked in the Central Appalachian region of the U.S.

Within each birth cohort, there are miners who may have died from any of the selected causes of death before they were able to apply for FBLP benefits. As a result, they are not included in the analysis. This is likely most pronounced in the earliest birth cohort in which relatively more miners may have died before having the chance to file for benefits, as the program was enacted in 1970.

The changes in proportional mortality from NMRD observed in this study may be independent of changes in another cause of death, but may also be influenced by changes in proportional mortality from another cause over time, i.e. a decrease in one cause may result in an increase in other causes rather than reflecting a true increase in mortality from these other causes. Proportional mortality is defined as the proportion of deaths within a specific population and time period attributable to specific causes of death, proportional mortality is not a mortality rate and can therefore not inform risk of death from a specific cause in this population. Instead, it can inform us as to the leading causes of death within a population at a specific time point. Consequently, results from this mortality study must be interpreted with this in mind and further analyses would be needed to determine an independent increasing trend of NMRD mortality in this population.

A limitation of our findings is the lack of data on smoking patterns in this population. Smoking data is not systematically collected by either the CWHSP or FBLP. Consequently, we are unable to assess the role of smoking rates on the changes in proportional mortality observed in this study. While smoking rates have declined among the general U.S. population, tobacco use among blue-collar workers, and miners in particular, remains high.[27,28] We observed a decrease in death from ischemic heart disease across the study period and across age groups. This trend is consistent with national data that indicate death from heart disease has been declining since the mid-1960s.[29]

6.0 Dissemination Efforts and Highlights

We have made a considerable effort to disseminate the findings from this research to all relevant stakeholders – including federal agencies, the broader scientific and medical community, and the general public. To date, we have concentrated dissemination efforts in three arenas: peer-reviewed journal publications, oral presentations at national and international scientific conferences, and interviews with the media. The completed and pending outcomes from these efforts are detailed below.

6.1 Published and planned manuscripts

1. Almberg KS, Cohen RA, Blackley DJ, Laney AS, Storey E, Halldin CN. Linking Compensation and Health Surveillance Data Sets to Improve Knowledge of US Coal Miners' Health. J Occup Environ Med. 2017;59(10):930-934. (*Published*)
2. Almberg KS, Halldin CN, Blackley DJ, Laney AS, Storey E, Rose CS, Go LHT, Cohen RA. Progressive Massive Fibrosis Resurgence Identified in U.S. Coal Miners Filing for Black Lung Benefits, 1970-2016. Ann Am Thorac Soc. August 2018. (*Published*)
3. Gandhi S, Almberg KS, Go L, Cohen RA. Lung Function Declines in Former Coal Mine Workers Absent Further Exposure. (*In process*)
4. Almberg KS, Go LH, Rose CS, Petsonk EL, Cohen RA. Progression of Radiographic Coal Workers' Pneumoconiosis Absent Further Exposure Among Former U.S. Coal Miners Applying for Federal Black Lung Benefits, 2000 - 2016 (*In process*)
5. Cause-specific mortality among U.S. coal miners participating in national surveillance and compensation programs, 1979 – 2016. (*In process*)

6.2 Presentations at national and international scientific conferences

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2. Almberg KS, Go LH, Rose CS, Petsonk EL, Graber JM, Harris G, Cohen RA. Progression of Radiographic Coal Workers Pneumoconiosis Absent Further Exposure Among Former U.S. Coal Miners Applying for Federal Black Lung Benefits, 2000 - 2013. In: D95. CHRONIC RESPIRATORY DISEASE IN THE MINING INDUSTRY. American Thoracic Society International Conference Abstracts. American Thoracic Society; 2017:A7313-A7313. *ATS Oral Presentation.* May 24, 2017.
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6.3 Dissemination of findings via the media

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8. Dr. Almberg discussed the findings of the PMF time-trend analysis with Dr. Gregory Tino for the podcast "Clinician to Clinician: an AnnalsATS Podcast" on November 20, 2018. This episode is currently being edited and will be released in early 2019. https://www.atsjournals.org/podcasts/annalsats

7.0 Conclusions and Impact Assessment

The research presented in this report has important implications for the federal programs that conduct medical surveillance on U.S. coal miners. Our first time linkage of CWHSP, FBLP, and NDI data underscores the gaps in current medical surveillance programs, indicating that nearly 40% of miners who file for federal benefits never participated in medical surveillance during active mining employment. Consequently, a large population of miners are not being screened for early stage disease, when there is an opportunity to reduce dust exposure for these workers and thereby diminish the risk of severe disease. In part as a result of these findings, NIOSH has focused efforts and resources on expanding participation in the CWHSP by trying to identify barriers to participation among active workers.

Our work on disease progression has contributed substantially to the understanding of radiographic progression of pneumoconiosis as well as continued lung function decline after a miner has left employment. Among former miners in the FBLP data, we found that nearly 4% of coal miners with no evidence of PMF at the time of initial CXR developed PMF by the time of their final CXR, with a mean interval between CXRs of 8.4 years. We found that a much larger percent (27%) of former miners applying for federal benefits, who showed normal lung function in initial tests, had accelerated lung function decline absent further exposure. These findings show that former miners with lung disease warrant continued medical monitoring for disease progression, and that former miners without evident disease at the end of their mining careers remain at risk for pneumoconiosis. Our findings also have implications for secondary prevention of lung disease among active coal miners, who may need to reduce or end their exposures to coal mine dust to minimize risk for progression. Our findings may also identify risk factors for severe

disease, such as geographic areas of high risk and higher risk cohorts which will allow focused investigation and interventions.

Our novel time-trend analysis of former miners with PMF confirms the increase in this severe disease among central Appalachian miners and suggests that this increase has been occurring since the 1990s. We identified 4,679 miners with PMF, as determined by the DOL, between 1970 and 2016. We found that the proportion of PMF cases among FBLP claimants has been increasing significantly since 1978, accelerating more steeply since 1996. We identified substantially larger numbers of miners with PMF (n = 2,474) than have been detected through national surveillance data of active miners (n = 225), underscoring the importance of monitoring miners after they have left the workforce.

Finally, our mortality analyses have shown that proportional mortality from non-malignant respiratory diseases, and specifically pneumoconioses, has increased across birth cohorts in the population, with the highest proportions observed in miners born after 1940. This increase is pronounced among younger miners and may reflect increased mortality from progressive massive fibrosis, which is occurring more frequently and in younger U.S. coal miners.

Our findings have been widely reported in the media and have contributed to the current national interest in coal miner health. We have shown the value of integrating datasets from different agencies and divisions within the federal government, and have laid the foundation for integrated analysis of these data to monitor future disease trends and to assess efficacy of primary prevention efforts.

8.0 Recommendations for Future Work

Our findings lay the groundwork for future efforts linking multiple data sets to monitor disease trends and determine efficacy of dust control efforts. The new MSHA regulations for coal mine dust exposure that went into effect in 2016 require medical surveillance with spirometry. Spirometry testing as well as expanded data collection on smoking and other personal risk factors have now been incorporated into the NIOSH CWHSP. In the future, this data can be linked in a similar fashion to the DOL FBLP data to provide a greater number of longitudinal data points for lung function. This will enable study of lung function impairment related to both coal mine dust exposure and smoking. There is also the opportunity to expand our work on mortality studies of this population. Cause of death data on all participants in these Federal Programs could be obtained and analyzed with respect to clinical indicators such as lung function, chest imaging findings, and mining tenure.

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10.0 Appendices

A. Almberg KS, Halldin, CN, Go LHT, Laney AS, Rose CS, Storey E, Cohen RA. Trends in mortality patterns among U.S. coal miners filing for Federal Black Lung Program benefits, 1970 to 2016. American Thoracic Society 2019 Annual Conference Submitted Abstract

Appendix A

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Trends in mortality patterns among U.S. coal miners filing for Federal Black Lung Program benefits, 1970 to 2016

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Abstract:
RATIONALE Coal miners suffer excess mortality from non-malignant respiratory diseases (NMRD), including pneumoconioses and chronic obstructive pulmonary disease (COPD). There is limited evidence of excess mortality from lung cancer and ischemic heart disease as well. The U.S. Department of Labor collects data on coal miners applying for Federal Black Lung Program benefits. Mortality data from this population has never been analyzed before and would be the largest study to date of cause of death in U.S. coal miners.
METHODS We obtained cause of death data from the National Death Index on former U.S. coal miners who previously applied for federal benefits and participated in the National Coal Workers' Health Surveillance Program (CWHSP). We characterized proportional mortality from selected underlying causes of death, employing Chi-square tests and logistic regression to test for significant trends across birth cohort and age group. Causes of death examined were non-malignant respiratory diseases, pneumoconioses excluding asbestosis, COPD, lung cancer, and ischemic heart disease (IHD).
RESULTS The study population included 34,771 deceased miners who had previously applied for federal benefits between 1970 and 2016 and had participated in the CWHSP. Average age and coal mine employment at time of death was 72 years and 26 years, respectively. NMRD accounted for 20% of the underlying cause of death in this population. Proportional mortality from NMRD increased significantly ($p<0.05$) among miners aged 65–74 born after 1930 (1930–1939, 28%; 1940–1970, 32%) compared to those born before 1930 (Table 1); a trend observed among deaths from COPD as well. Proportional mortality from NMRD, specifically pneumoconioses, among younger miners (<65 years) increased significantly in the most recent
birth cohort compared to earlier birth cohorts. Proportional mortality from lung cancer was significantly elevated among older miners (19%) in the most recent birth cohort (from 1940 onward) compared to miners of the same age in previous cohorts (7–11%). Proportional mortality from IHD decreased significantly over successive birth cohorts.
CONCLUSION Proportional mortality from NMRD, and specifically pneumoconioses, increased across birth cohorts, with the highest proportions observed in miners born after 1940. This increase is pronounced among younger miners and may reflect increased mortality from progressive massive fibrosis, which is occurring more frequently and in younger U.S. coal miners. The increased proportional mortality from lung cancer in the most recent birth cohort may reflect exposure to workplace carcinogens (e.g., diesel exhaust, respirable silica) for which further analysis is planned.

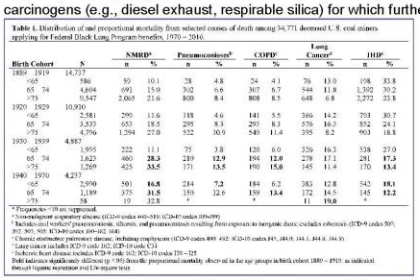

Table 1. Distribution of and proportional mortality from selected causes of death among 34,771 deceased U. S. coal miners applying for Federal Black Lung Program benefits, 1970 – 2016.

Birth Cohort	N	NMRD[a]		Pneumoconioses[b]		COPD[c]		Lung Cancer[d]		IHD[e]	
		n	%	n	%	n	%	n	%	n	%
1880 – 1919	14,737										
<65	580	59	10.1	28	4.8	24	4.1	76	13.0	198	33.8
65 – 74	4,604	692	15.0	302	6.6	307	6.7	544	11.8	1,392	30.2
>75	9,547	2,065	21.6	809	8.4	808	8.5	648	6.8	2,272	23.8
1920 – 1929	10,930										
<65	2,581	299	11.6	118	4.6	141	5.5	366	14.2	793	30.7
65 – 74	3,535	653	18.5	295	8.3	293	8.3	576	16.3	852	24.1
>75	4,796	1,294	27.0	532	10.9	549	11.4	395	8.2	903	18.8
1930 – 1939	4,887										
<65	1,955	222	11.1	75	3.8	120	6.0	326	16.3	538	27.0
65 – 74	1,623	460	**28.3**	210	**12.9**	194	**12.0**	278	17.1	281	**17.3**
>75	1,269	423	**33.5**	171	**13.5**	195	**15.8**	145	11.4	170	**13.4**
1940 – 1970	4,237										
<65	2,950	501	**16.8**	214	**7.2**	184	6.2	383	12.8	542	**18.1**
65 – 74	1,189	375	**31.5**	150	12.6	159	**13.4**	172	14.5	145	**12.2**
>75	98	19	32.8	*	*	*	*	11	19.0	*	*

* Frequencies < 10 are suppressed.
[a] Non-malignant respiratory disease (ICD-9 codes 460–519; ICD-10 codes 10–99)
[b] Includes coal workers' pneumoconiosis, silicosis, and pneumoconiosis resulting from exposure to inorganic dusts; excludes asbestosis (ICD-9 codes 500, 502, 505, 523; ICD-10 codes 160–162, J60)
[c] Chronic obstructive pulmonary disease, including emphysema (ICD-9 codes 490–492, 496; ICD-10 codes J40–J44, J47)
[d] Lung cancer includes ICD-9 code 162; ICD-10 code C34
[e] Ischemic heart disease includes ICD-9 code 410; ICD-10 codes I20 – I25
Bold indicates significantly different ($p < 0.05$) from the proportional mortality observed in the five age groups in birth cohort 1880 – 1919, as indicated through logistic regression and Chi-square test

;

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