Accepted: 13 June 2018
DOI: 10.1002/ajim.22890

RESEARCH ARTICLE

WILEY AMERICAN JOURNAL OF INDUSTRIAL MEDICINE

# High exposure mining occupations are associated with obstructive lung disease, National Health Interview Survey (NHIS), 2006-2015

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**Funding information**
National Institute for Occupational Safety and Health (NIOSH) Training Program, Grant number: T42/OH008672

**Background:** The association between mining occupation categories and obstructive lung disease (OLD) has not been well explored in the United States.
**Methods:** National Health Interview Survey (NHIS) data from 2006 to 2015 was used to determine the relationship between mining occupations and diagnosis of chronic bronchitis, emphysema, chronic obstructive pulmonary disease (COPD), and asthma. We classified occupations into low, moderate, high, and very high dust exposure groups. Extraction workers were categorized as very high dust exposure.
**Results:** We found 4.5% of miners had chronic bronchitis, 3.3% had emphysema, 6.2% had COPD, and 9.9% had asthma. In fully adjusted models, extraction workers had significantly increased odds of having chronic bronchitis (OR = 2.18 [95%CI: 1.02, 4.64]), emphysema (OR = 7.85 [95%CI: 1.70, 36.27]), and COPD (OR = 2.56 [95%CI: 1.29, 5.12]) compared to lower exposure occupations.
**Conclusions:** Occupation is an important predictor of OLD in the mining industry

KEYWORDS
COPD, emphysema, mining, NHIS, occupation

## 1 | BACKGROUND

Chronic obstructive pulmonary disease (COPD) includes emphysema and chronic bronchitis. It was the 3rd leading cause of death in the United States in 2014, with 15.7 million people (6.4%) having been diagnosed with COPD.[1,2] The American Thoracic Society estimated that approximately 15% of all COPD cases are attributable to occupational exposures.[3] Other studies have shown a population attributable risk (PAR) of occupational COPD of to up to 20%.[4,5] The overall prevalence of COPD in the US working population from 1997 to 2004 was 4.0% (95% confidence interval [CI]: 3.9, 4.1%) with COPD prevalence being higher in females, and higher in whites compared to other racially defined groups.[6] This trend was also observed in an analysis of working adults aged 40-79 years from 2004 to 2011; the overall estimated prevalence of COPD was 4.2% (95%CI: 4.0, 4.3) and higher among females and whites.[7]

In addition to COPD, an estimated 9-15% of new-onset asthma in adults residing in industrialized countries is attributable to occupational factors.[8] Exposure to inorganic dust has been shown to be strongly associated with severe asthma exacerbations.[9] The asthma prevalence of workers in the mining industry is among the highest of occupations in the United States.[10] Workers in mining occupations are at significant risk for Obstructive Lung Disease (OLD) due to their mineral dust exposures. Exposure to respirable mineral dust has been shown to: (i) damage the lung parenchyma which may lead to fibrotic disease such as coal worker's pneumoconiosis and silicosis or result in emphysema with its resultant obstructive impairment and (ii) damage airways resulting in chronic bronchitis, and other mineral dust airway diseases.[11]

Institution at which the work was performed: University of Illinois at Chicago.

  

Exposure to mine dust has been associated with significant lung function impairment.[12,13] The extent of exposure has been clearly related to the prevalence and severity of OLD using a number of outcomes including symptoms of chronic bronchitis, the degree of lung function impairment, and the extent of emphysema.[12,14–16] Studies have shown reduced lung function in miners and former-miners compared to non-miners of the same age. Up to 20% of mine workers were found to have a forced expiratory volume in 1 s ($FEV_1$) of less than 80% of reference indicating significant disease.[17] A systematic review of occupational dust exposure and COPD showed that an estimated 80 of 1000 nonsmoking coal miners with a cumulative respirable dust exposure of 122.5 gh/m$^3$ (equivalent to 35 years of work at the pre-2016 permissible exposure limit of 2 mg/m$^3$) would be expected to have a >20% loss of $FEV_1$ due to dust.[18]

The severity and prevalence of most mining-related respiratory diseases such as emphysema and chronic bronchitis have also been shown to be a function of commodity, intensity of respirable dust exposure, tenure (period of exposure), and host susceptibility.[6,19–22] In the United States, emphysema prevalence among miners is higher among older workers and cigarette smokers.[16] The construction and extraction occupations were significantly associated with an increased odds of chronic bronchitis (odds ratio [OR] = 1.33, [95% CI: 1.00, 1.88]) in adults aged 40-70 years old in the US working population from 1997 to 2004.[7]

Mining remains an important sector in the US workforce with significant numbers of workers at risk for OLD. From 2006 to 2015, the sand and gravel industry (47.8%) had the highest number of active mines followed by stone (31.5%), coal (13.3%), nonmetal mines (5.3%), and metal mines (2.2%).[23] There were 14 885 active mines in the United States in 2006, but only 13 294 by 2015.[23] In 2015, the US mining industry employed an estimated 194 065 individuals in surface mining operations and 43 747 individuals in underground mining operations.[23] The total number of mine employees has dropped since 2006 when there were 270 270 employees of which 223 227 (81.3%) were surface workers and 47 043 were underground employees (18.7%).[24]

Occupational category has been reported to be superior to industry in studies attempting to correlate exposures with health outcomes.[19] Dust exposures have been reported to vary significantly by occupations in coal miners[25] which would influence the prevalence and severity of dust-related lung disease. However, the association between mining occupation and mineral dust lung diseases within the mining industry has not been explored in the United States. with the purpose of identifying specific risk groups by occupation. We used data from the National Health Interview Survey (NHIS) to address this gap in knowledge about the relationship between occupation within the mining industry and OLD. The NHIS is a reliable public health surveillance database useful for determining the existence and magnitude of work-related health conditions, and analyzing potentially hazardous working conditions that need to be mitigated.[26] The main objective of this study was to assess differences in the prevalence of OLD across different job titles in the US mining industry using NHIS data from 2006 to 2015. The occupational diseases of interest were chronic bronchitis, emphysema, COPD, and asthma.

## 2 | METHODS

### 2.1 | Data source

The NHIS is one of the largest and main sources of health information in the United States. It was established in 1957 to monitor progress toward national health objectives, evaluate health policies and programs, and track changes in health behaviors and health care use.[27] The NHIS is an annual cross-sectional survey of non-institutionalized Americans conducted by the National Center for Health Statistics (NCHS).[27] Informed consent is obtained from all individuals and the NCHS Research Review Board approves each year's study protocol.[27] Questionnaires, documentation, and data files are publicly available at https://www.cdc.gov/nchs/nhis/.

### 2.2 | Study design

This study included adult participants (aged 18 years and older) of the 2006-2015 NHIS adult subsample, who were employed (ie, worked for pay) in the mining industry. To create a unique person identifier (PUBLICID), the year of survey (SRVY_YR), the household serial number (HHX), the family number (FMX), and the person number (FPX) from the adult sample were combined as recommended by NHIS prior to merging data from 2006 to 2015. We employed NHIS industry codes based on the National Occupational Research Agenda and occupation codes based on the Standard Occupational Classification (SOC). Demographic data collected in the NHIS include sex, age, race, and smoking status. Age was categorized into seven groups based on 10-year increments from <24 years old to ≥75 years old for descriptive statistical purposes. Smoking was categorized into three groups (current smoker, former smoker, and never smoker), and race was categorized as black, white, and other.

### 2.3 | Identification of mining occupations

The NHIS collects employment information from each participant including the industry and occupation in which they currently work, where they have worked in the past week and/or past 12 months, and where they have been employed the longest. The number of years in which a participant worked in their longest held position is also collected: “Thinking of all the jobs or businesses you have ever had, including work done in the Armed Forces, for whom did you work the longest (Name of company, business, organization or employer)”; Longest tenure (WRKLGLHN), “About how long did you work at the job or business you held the longest”; and number of years in their current job (YRSWRKPA), etc. Persons with an industry code of “Mining Industries (2)” were classified as miners. Individuals with industry codes relating to oil and gas extraction (0370) were excluded. Consequently, the analysis only included individuals who were miners (codes 0380, 0390, 0470, 0480) and those who were involved in mining support activities within mines (code 0490) (Figure 1). Individuals who either refused to respond to questions of select covariates or those whose information was

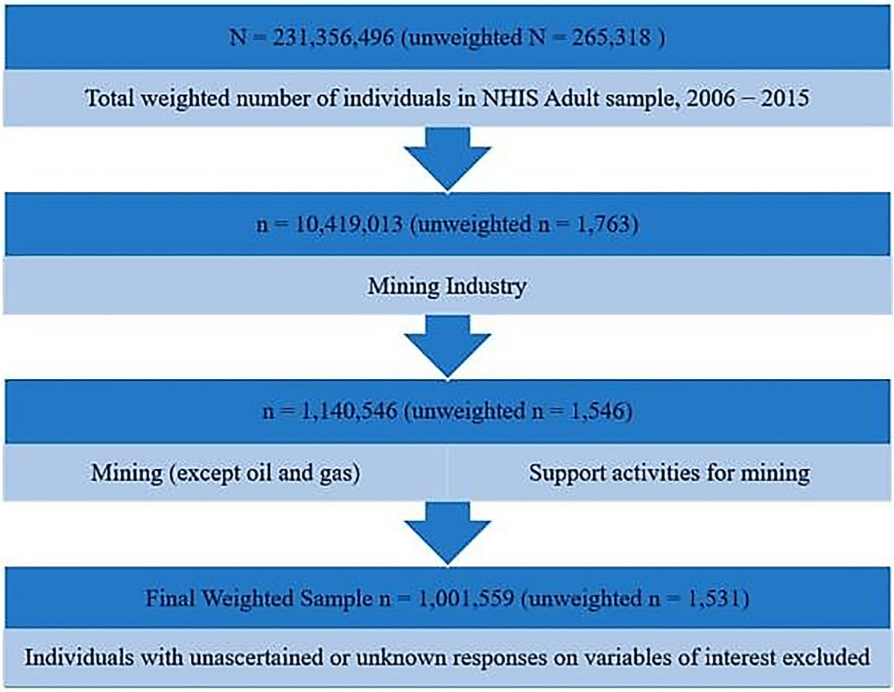


**FIGURE 1** Identification of individuals in the mining industry from the National Health Interview Survey (NHIS) for study inclusion, 2006-2015

unascertained or unknown were excluded from the analysis (*n* = 15 respondents).

## 2.4 | Case definition

Obstructive lung diseases (OLDs) evaluated in this study included emphysema, chronic bronchitis, COPD, and asthma. Emphysema was defined as individuals who answered "yes" to the question "Have you ever been told by doctor or other health professional that you have emphysema?" Chronic bronchitis was defined as individuals who answered "yes" to the question "During the past 12 months, have you been told by doctor or other health professional that you have chronic bronchitis?" COPD was defined as an individual who answered "yes" to either ever having been told they had emphysema or having had chronic bronchitis in the past 12 months. Individuals with asthma answered "yes" to the question "Have you ever been told by doctor or other health professional that you have asthma?"

## 2.5 | Occupational risk groups

Due to the small number of unweighted cases in certain occupations, mining-related occupations were grouped a priori into four risk groups based on prior studies of mining occupations and occupations descriptions from SOC and NHIS (Figure 2). Group 1 represents low dust exposure jobs; Group 2 includes jobs with moderate exposures; Group 3 represents high exposure jobs; and Group 4 represents very high exposure jobs containing extraction workers who are considered to be at the highest risk for dust exposure.

Occupations that were related to office work and management were grouped into the low exposure group (Group 1). A study of office workers and school workers in the general US investigating predictors of COPD showed that office and school workers had a lower population prevalence of COPD compared to other workers (4.7% vs 8.1%).[28] The risk of COPD in office workers and school workers was associated with increased employment duration, cigarette smoking, alcohol use, and use of propane fuel at home, and the risk of COPD was higher among whites.[28]

Architecture and engineering; building and grounds cleaning and maintenance; protective services; and Life, Physical, and Social Science occupations were considered as moderate exposure jobs (Group 2) based on previous data from an NHIS study of COPD.[6] Moreover, since architects and engineers may occasionally work at the face of the mine, they may have comparatively higher exposure than office workers.

The high exposure group (Group 3) included construction, transportation and moving, installation, maintenance and repair, and production. This group included mining and construction supervisors; construction trade workers such as boilermakers and carpenters, electricians, and painters; helpers of the construction trade workers; and other construction-related workers.[29] In a study of exposure to respirable dust and quartz in a coal mine, underground transportation and moving had significantly lower respirable dust compared to extraction workers (drillers, bolters, long wall operators, and blasters).[30] Moreover, a South African study of coal miners also showed higher concentration of silica in respirable dust at the face of the mine and among continuous miners operators compared to other jobs

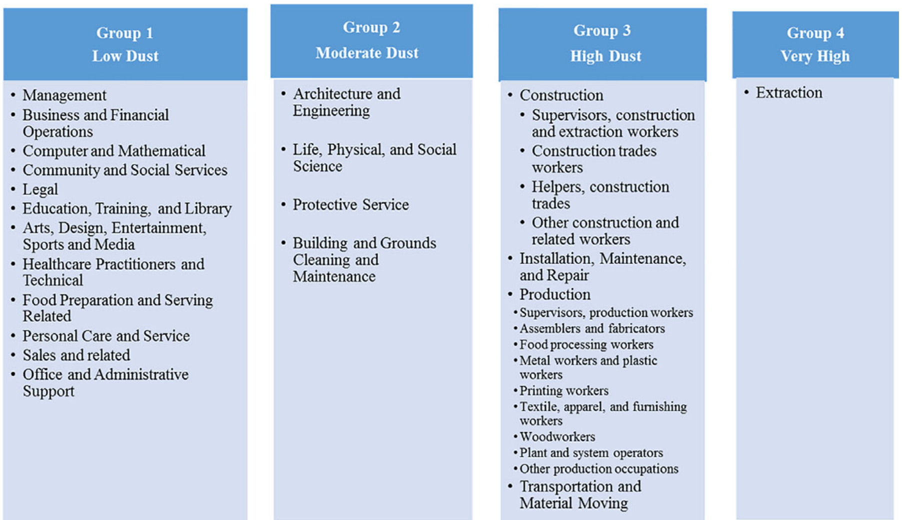


**FIGURE 2** Classification of occupations in the mining industry based on the likelihood and intensity of mine dust exposure, NHIS, 2006-2015

further from the face of the mine.[31] Production workers (in Group 3) were classified as having less dust exposure compared to extraction workers.[29] According to the SOC, production workers include plant and system operators, woodworkers, printing workers, metal and plastic workers, assemblers, and fabricators.[29] In a study of US surface coal miners, cleaning plant operators, coal truck drivers, and welders were the bottom five of the top 10 dustiest jobs, while drillers were among the top three.[32]

Extraction workers (drillers, blast/explosive technicians, long wall operators, roof bolters, etc.) were considered to be in the very high dust exposure group (Group 4) in this analysis. Respirable mine dust levels are highest for workers near the face of the mine compared to those working farther from the face, and are particularly high for those performing drilling, blasting, and roof bolting.[33–34] In US coal mines, there is evidence to show that certain mining occupations (continuous miner operators, cutting machine operators, long wall drill operators, and roof bolters) had exposure to dust containing more than 5% quartz, and to quartz concentrations that were more than 100 $\mu g/m^3$.[34] Another study of Tanzanian coal mines found drilling to be associated with the highest exposure to respirable dust (17.37 $mg/m^3$), and showed that blasting and pneumatic drilling times were major determinants of respirable dust and quartz.[30]

## 2.6 | Statistical analysis

Demographic characteristics and the prevalence (%) of each disease (chronic bronchitis, emphysema, COPD, and asthma) were determined. Separate bivariate and multivariable logistic regression models were built to analyze the odds of OLD in US miners in the four occupational risk groups. Statistical analyses accounted for the complex survey design of NHIS that involves stratification, multistage sampling, and a probability cluster sampling technique with oversampling of minorities. As a result, sampling weights were incorporated. The adult subsample weights were divided by 10 since we combined ten survey cycles (2006-2015). A subgroup of miners was created from the main dataset to facilitate our primary analyses. In logistic regression models, the low exposure group (Group 1) was used as the reference group.

Crude models and models adjusted for age (continuous), smoking status (current, ex-smoker, never smoker), sex (male, female), and race (black, white, other) were used to determine the association of occupational group based on exposure risk (low, medium, high, very high) and select health outcomes (chronic bronchitis, emphysema, COPD, and asthma). Body mass index (BMI) did not confound the association between occupational exposure groups and OLD, so it was not included in final adjusted models. All analyses were performed using SAS® 9.4 software (SAS Institute Inc., Cary, NC). PROC SURVEYFREQ, PROC SURVEYMEANS, and PROC SURVEYLOGISTIC procedures were used to analyze data.

# 3 | RESULTS

There were 1531 US adults employed in the mining industry who participated in the NHIS between 2006 and 2015, representing a weighted mining population of 1 001 559. Of those individuals in the mining industry, 78% had worked in the mining industry for more than 2 years and 22.5% had a tenure of 20 years or more in the industry. Moreover, 44.3% had mining as their longest job and 44.7% were never smokers. The mean age was 49 years (standard deviation = 0.69) and the average BMI was 29.8 (standard deviation = 0.40).

Table 1 shows the unweighted and weighted number of employees for all occupations within the mining industry. Some occupations had a small number of unweighted cases; therefore, the weighted number of cases and the prevalence for those occupations may potentially be unreliable. The coefficient of variation (CV) was

**TABLE 1** Distribution of obstructive lung disease (OLD) by occupation in the general U.S. mining population; NHIS, 2006-2015[a]

| | N = Total miners | | Chronic bronchitis | | Emphysema | | COPD | | Asthma | |
|---|---|---|---|---|---|---|---|---|---|---|
| Occupations | N | N (weighted) | N | N (weighted) | N | N (weighted) | N | N (weighted) | N | N (weighted) |
| Management | 122 | 87 104 | 4 | 2289 | 4 | 2238 | 8 | 4527 | 17 | 9972 |
| Business and financial operations | 47 | 26 238 | 2 | 1651 | 0 | 0 | 2 | 1651 | 7 | 5284 |
| Computer and mathematical | 12 | 7772 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Architecture and engineering | 74 | 56 550 | 6 | 3724 | 1 | 53 409 | 6 | 3724 | 10 | 9163 |
| Life, physical, and social science | 39 | 30 763 | 0 | 0 | 1 | 26 301 | 1 | 26 301 | 4 | 1578 |
| Community and social services | 1 | 1182 | 1 | 1182 | 0 | 0 | 1 | 1182 | 1 | 1182 |
| Legal | 4 | 2488 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Education, training, and library | 3 | 2727 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Arts, design, entertainment, sports, and media | 3 | 2189 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Healthcare practitioners and technical | 1 | 1005 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Protective service | 4 | 4587 | 1 | 42 405 | 0 | 0 | 1 | 42 405 | 0 | 0 |
| Food preparation and serving-related | 5 | 2325 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Building and grounds cleaning and maintenance | 11 | 7024 | 0 | 0 | 1 | 68 604 | 1 | 68 604 | 1 | 68 604 |
| Personal care and service | 1 | 18 901 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sales and related | 12 | 9402 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 94 103 |
| Office and administrative support | 121 | 85 197 | 7 | 3875 | 0 | 0 | 7 | 3875 | 11 | 8561 |
| Construction and extraction | 646 | 383 355 | 36 | 22 154 | 44 | 24 324 | 59 | 34 450 | 70 | 36 645 |
| Installation, maintenance, and repair | 129 | 82 633 | 7 | 3417 | 3 | 2363 | 8 | 3851 | 11 | 2945 |
| Production | 119 | 80 973 | 1 | 36 506 | 1 | 37 904 | 2 | 745 | 6 | 4580 |
| Transportation and material moving | 177 | 127 855 | 10 | 6552 | 5 | 1613 | 12 | 7372 | 18 | 17 797 |
| Total | 1531 | 1 001 559 | 75 | 45 633 | 60 | 32 402 | 108 | 62 749 | 158 | 99 334 |

NHIS, National Health Interview Survey; COPD, chronic obstructive pulmonary disease.
[a]Statistical analyses accounted for the complex, multi-stage survey design of the NHIS that involves stratification, clustering, and oversampling of specific population subgroups. Sample weights were incorporated to ensure calculation of valid estimates. Depending on the sample weights, each respondent represents a certain number of non-institutionalized residents in the United States.

used as a tool to evaluate the reliability of the population prevalence estimates. The CV is the ratio of the standard deviation to the mean.[35] The CV for a single variable describes the dispersion of the variable; the higher the CV, the greater the dispersion in the variable.[35] Typically, a prevalence estimate with a CV of <30% is considered reliable, estimates with a CV ranging between 30 and 50% are considered moderately unreliable, and estimates with higher CVs are considered unreliable.[36] Following guidelines from the NCHS, prevalence estimates with CVs >50% were not reported in this analysis.[36]

Table 2 shows the prevalence of OLD health outcomes by select demographic characteristics. Chronic bronchitis was highest among individuals 55-64 years old, racially defined groups other than white or black, and females. The prevalence of emphysema and COPD prevalence increased with age. Also, COPD prevalence was slightly higher in females (6.7%) compared to males (6.2%). In contrast with all the other respiratory health outcomes, asthma prevalence was higher (10.2%) in younger adults (45-54 years old). Individuals who were overweight had the highest prevalence of OLD identified in this analysis.

The number of cases and the prevalence estimates of chronic bronchitis, emphysema, COPD, and asthma varied by exposure risk group within the US mining industry (Table 3). The prevalence of chronic bronchitis (7.3%), emphysema (6.9%), and COPD (10.5%) was highest among extraction workers in this analysis compared to other exposure groups in the mining industry. The overall mining industry prevalence of chronic bronchitis was 4.5% ($n = 45\,633$), while 3.3% ($n = 32\,401$) had emphysema, 6.2% ($n = 62\,750$) had COPD, and 9.9% ($n = 99\,335$) had asthma.

In bivariate analyses, both chronic bronchitis and emphysema were significantly associated with being a current smoker or former smoker compared to those who never smoked (Table 4). In particular, former smokers showed a fivefold increase in the odds of emphysema compared to those who never smoked (OR = 5.48

**TABLE 2** Weighted number of cases and prevalence (%) of obstructive lung disease (OLD) by demographic characteristics in the general U.S. mining population; NHIS, 2006-2015

| | | Chronic bronchitis | | Emphysema | | COPD | | Asthma | |
|---|---|---|---|---|---|---|---|---|---|
| Covariates | *N* | Cases | Prevalence | Cases | Prevalence | Cases | Prevalence | Cases | Prevalence |
| Age (years) | | | | | | | | | |
| <24 | 80 688 | 1894 | –[b] | –[c] | –[c] | 1894 | –[b] | 20 788 | 25.76 |
| 25-34 | 195 131 | 6910 | 3.54[a] | –[c] | –[c] | 6910 | 3.54[a] | 15 625 | 8.01 |
| 35-44 | 156 617 | 4422 | –[b] | –[c] | –[c] | 4422 | –[b] | 9855 | 6.29[a] |
| 45-54 | 174 353 | 4837 | 2.77[a] | 1343 | –[b] | 5208 | 2.99[a] | 17 825 | 10.22 |
| 55-64 | 172 753 | 12 969 | 7.5[a] | 10 229 | –[b] | 15 919 | 9.21[a] | 13 932 | 8.06 |
| 65-74 | 120 504 | 8043 | 6.67 | 10 599 | 8.80 | 14 739 | 12.23 | 14 581 | 12.10 |
| >=75 | 101 513 | 6558 | 6.46 | 10 230 | 10.08 | 13 658 | 13.45 | 6729 | 6.63[a] |
| Race | | | | | | | | | |
| White | 880 188 | 38 867 | 4.42 | 29 456 | 3.35 | 55 108 | 6.26 | 87 077 | 9.89 |
| Black | 58 262 | 2870 | –[b] | 731 | –[b] | 3601 | –[b] | 6758 | –[b] |
| Other | 63 109 | 3896 | 6.17[a] | 2214 | –[b] | 4039 | 6.40[a] | 5499 | 8.71[a] |
| Sex | | | | | | | | | |
| Male | 883 224 | 39 601 | 4.48 | 30 546 | 3.46 | 54 862 | 6.21 | 85 987 | 9.74 |
| Female | 118 335 | 6032 | 5.10[a] | 1855 | –[b] | 7887 | 6.66[a] | 13 348 | 11.28[a] |
| Smoker | | | | | | | | | |
| Never | 443 100 | 11 276 | 2.54[a] | 5246 | 1.18[a] | 16 063 | 3.63 | 41 766 | 9.43 |
| Current | 251 206 | 12 001 | 4.78[a] | 8216 | 3.27[a] | 15 589 | 6.21[a] | 26 142 | 10.41 |
| Former | 307 253 | 22 356 | 7.28 | 18 940 | 6.16[a] | 31 096 | 10.12 | 31 426 | 10.23 |
| BMI | | | | | | | | | |
| Underweight | 8329 | 2612 | –[b] | 179 | –[b] | 2612 | –[b] | 767 | –[b] |
| Obese | 321 125 | 14 539 | 4.53 | 6671 | 2.08[a] | 16 741 | 5.21 | 36 360 | 11.32 |
| Overweight | 397 994 | 16 657 | 4.19 | 15 506 | 3.90 | 27 778 | 6.98 | 48 072 | 12.08 |
| Normal | 274 111 | 11 825 | 4.31 | 10 046 | 3.66 | 15 617 | 5.70 | 14 136 | 5.16 |

NHIS, National Health Interview Survey; COPD, chronic obstructive pulmonary disease.
All coefficients of variation are <30% unless otherwise indicated.
[a]Coefficient of variation of the estimate is 30-50%; the estimate is unreliable.
[b]Coefficient of variation of the estimate exceeds 50%.
[c]No cases.

[95%CI: 5.47, 5.48]). Also, compared to individuals 45-54 years old (there were no persons younger who had emphysema), persons 55 years and older had higher odds of emphysema. Furthermore, bivariate analysis showed that being an extraction worker was strongly associated with emphysema compared to miners in the low exposure risk group. COPD was also strongly associated with age, specifically in adults 55 years and older, smoking, and employment in extraction occupations. There was no significant

**TABLE 3** Prevalence (%) of obstructive lung disease (OLD) by occupational risk groups in the general U.S. mining population; NHIS, 2006-2015

| | Chronic bronchitis | | Emphysema | | COPD | | Asthma | |
|---|---|---|---|---|---|---|---|---|
| Exposure group[a] | Cases | Prevalence | Cases | Prevalence | Cases | Prevalence | Cases | Prevalence |
| Low | 8996 | 3.95[b] | 2238 | –[c] | 11 234 | 4.93[b] | 25 941 | 11.39 |
| Moderate | 4148 | 4.19[b] | 1484 | 1.50[b] | 5098 | 5.15[b] | 11 427 | 11.55[b] |
| High | 12 618 | 3.12 | 9941 | 2.46 | 18 079 | 4.47 | 34 424 | 8.52 |
| Very high | 19 871 | 7.3[b] | 18 739 | 6.92 | 28 338 | 10.47 | 27 542 | 10.18 |
| Overall prevalence | | 4.51 | | 3.25 | | 6.24 | | 9.91 |

NHIS, National Health Interview Survey; COPD, chronic obstructive pulmonary disease.
[a]Refer to Figure 2 for definition of categories.
[b]Coefficient of variation of the estimate is 30-50%; the estimate is unreliable.
[c]Coefficient of variation of the estimate exceeds 50%.

**TABLE 4** Bivariate analysis of obstructive lung disease (OLD) by covariates in the general U.S. mining population; NHIS, 2006-2015

| | Chronic bronchitis | | Emphysema | | COPD | | Asthma | |
|---|---|---|---|---|---|---|---|---|
| **Covariates** | **OR** | **(95%CI)** | **OR** | **(95%CI)** | **OR** | **(95%CI)** | **OR** | **(95%CI)** |
| Age (years) | | | | | | | | |
| <24 | Reference | | Reference | | Reference | | Reference | |
| 25-34 | 1.53 | (0.44, 5.30) | – | – | – | – | 0.25 | (0.13, 0.49) |
| 35-44 | 1.21 | (0.18, 8.12) | – | – | 1.21 | (0.18, 8.12) | 0.19 | (0.07, 0.53) |
| 45-54 | 1.19 | (0.26, 5.51) | – | – | 1.28 | (0.27, 6.00) | 0.33 | (0.13, 0.81) |
| 55-64 | 3.38 | (0.55, 20.78) | **8.11** | **(1.37, 47.99)** | 4.22 | (0.68, 26.18) | 0.25 | (0.12, 0.54) |
| 65-74 | 2.98 | (0.55, 16.08) | **12.42** | **(2.43, 63.44)** | **5.80** | **(1.09, 30.75)** | 0.40 | (0.17, 0.92) |
| >=75 | 2.87 | (0.48, 17.16) | **14.43** | **(2.91, 71.58)** | **6.47** | **(1.15, 36.47)** | 0.21 | (0.08, 0.54) |
| Race | | | | | | | | |
| White | Reference | | Reference | | Reference | | Reference | |
| Black | 1.12 | (0.28, 4.45) | 0.37 | (0.06, 2.10) | 0.99 | (0.30, 3.30) | 1.20 | (0.53, 2.68) |
| Other | 1.42 | (0.64, 3.15) | 1.05 | (0.34, 3.29) | 1.02 | (0.47, 2.25) | 0.87 | (0.41,1.86) |
| Sex | | | | | | | | |
| Female | Reference | | Reference | | Reference | | Reference | |
| Male | 0.87 | (0.34, 2.26) | 2.25 | (0.69, 7.34) | 0.93 | (0.37, 2.34) | 0.85 | (0.42, 1.71) |
| Smoker | | | | | | | | |
| Never | Reference | | Reference | | Reference | | Reference | |
| Current | **1.92** | **(1.92, 1.92)** | **2.82** | **(2.82, 2.82)** | 1.76 | (0.73, 4.24) | 1.12 | (0.59, 2.11) |
| Former | **3.01** | **(3.00, 3.01)** | **5.48** | **(5.47, 5.48)** | **2.99** | **(1.21, 7.43)** | 1.10 | (0.64, 1.87) |
| Exposure Group[a] | | | | | | | | |
| Low | Reference | | Reference | | Reference | | Reference | |
| Moderate | 1.07 | (0.40, 2.83) | 1.54 | (0.32, 7.29) | 1.05 | (0.49, 2.26) | 1.02 | (0.33, 3.12) |
| High | 0.78 | (0.38, 1.61) | 2.54 | (0.64, 10.18) | 0.90 | (0.47, 1.74) | 0.73 | (0.40, 1.32) |
| Very High | **1.93** | **(0.80, 4.66)** | **7.50** | **(1.96, 28.68)** | **2.25** | **(1.10, 4.61)** | 0.88 | (0.47, 1.66) |

NHIS, National Health Interview Survey; COPD, chronic obstructive pulmonary disease.
Significant associations are given in bold.
[a]Refer to Figure 2 for definition of categories.

increase in odds of asthma in individuals in the mining industry in bivariate analyses.

In the fully adjusted models, compared to low exposure occupations, individuals in the very high exposure group had significantly increased odds of chronic bronchitis (OR = 2.18 [95%CI: 1.02, 4.64]), emphysema (OR = 7.85 [95%CI: 1.70, 36.27]), and COPD (OR = 2.56 [95%CI: 1.29, 5.12]) (Table 5). There was no significant association between any exposure risk group and asthma when compared to the low exposure occupation group in fully adjusted models.

**TABLE 5** Association[a] of occupational risk exposure groups and obstructive lung disease (OLD) in the general U.S. mining population; NHIS, 2006-2015

| | | Chronic bronchitis | | Emphysema | | COPD | | Asthma | |
|---|---|---|---|---|---|---|---|---|---|
| **Exposure group[b]** | ***N*** | **OR** | **(95%CI)** | **OR** | **(95%CI)** | **OR** | **(95%CI)** | **OR** | **(95%CI)** |
| Low | 227 818 | Reference | | Reference | | Reference | | Reference | |
| Moderate | 98 925 | 1.37 | (0.50, 3.74) | 2.01 | (0.38, 10.63) | 1.39 | (0.62, 3.14) | 1.02 | (0.28, 3.77) |
| High | 404 131 | 0.88 | (0.42, 1.84) | 3.00 | (0.65, 36.27) | 1.04 | (0.56, 1.95) | 0.72 | (0.34, 1.52) |
| Very High | **270 685** | **2.18** | **(1.02, 4.64)** | **7.85** | **(1.70, 36.27)** | **2.56** | **(1.29, 5.12)** | 0.87 | (0.39, 1.95) |

NHIS, National Health Interview Survey; COPD, chronic obstructive pulmonary disease.
Significant associations are given in bold.
[a]Adjusted for race (black, white, other), smoking status (current, ex-smoker, never smoker), age (continuous), and sex (male, female).
[b]Refer to Figure 2 for definition of categories.

## 4 | DISCUSSION

Among individuals working in the mining industry from 2006 to 2015, the overall estimated prevalence of self-reported, doctor-diagnosed, chronic bronchitis was 4.5%; emphysema was 3.3%; COPD was 6.2%; and asthma was 9.9%. Prevalence of chronic bronchitis, emphysema, and COPD increased with increasing age, and was highest among former smokers. Our results are consistent with other findings such as those from the Behavioral Risk Factor Surveillance System study which showed that the prevalence of self-reported doctor-diagnosed chronic bronchitis, emphysema, and COPD among all US adults in 2011 increased with age.[37] US investigators found similar results in an analysis of US working adults aged 40-70 years old.[20]

Our findings are consistent with literature that has shown a significant association between mining and chronic bronchitis, emphysema, and COPD.[17,38–44] Within the mining industry, however, we found that extraction workers had significantly elevated odds of chronic bronchitis, emphysema, and COPD compared to low exposure occupations. These findings suggest that the risk of lung disease is not uniform across all those employed in the mining industry, but that extraction occupations within the mining industry have a higher risk of COPD, while we observed no statistically significant differences between the other occupational groups. Since extraction workers such as drillers have the highest exposure to mine dust,[30] these findings are consistent with our hypothesis. Our findings indicate that job title, which in some cases can be a surrogate for intensity of dust exposure within the mining industry, may be an additional predictor of chronic bronchitis, emphysema, and COPD.

In final multivariable models, the relationship between extraction occupations and lung disease persisted after controlling for smoking history, supporting the hypothesis that exposure to respirable mineral dust is associated with the development of COPD independent of smoking.

We found the prevalence of asthma was highest in the low and moderate occupational exposure groups. The NHIS determined asthma status by asking if an individual had “ever been told by a doctor or health professional if they had asthma.” This broad definition of asthma likely captures many cases of childhood asthma. Childhood asthma could not be eliminated in this analysis as the variables for childhood asthma; “less than 16 when you were first told you had asthma” or “age when you were first told you had asthma” were unreliable. However, the decline in asthma prevalence with increasing age and exposure is consistent with healthy worker effect. This has previously been reported among miners using airway responsiveness as an indicator of asthma.[45]

Disturbingly, in the last decade, the incidence of mine dust-related diseases have shown an increase.[40,46] Data from underground silver mines, copper mines, and mills producing nonmetallic minerals have shown that more than 50% of samples exceeded the permissible exposure limits: some mills had a mean of 43% silica content in dust samples.[47] In part as a response to these trends, The Mine Safety and Health Administration (MSHA) and the Occupational Safety and Health Administration (OSHA) have intensified efforts to reduce exposure to mineral dust by implementing new regulations. In 2016, OSHA implemented a new crystalline silica rule to drastically reduce mineral dust-related lung diseases by reducing the permissible exposure limit (PEL) for respirable crystalline silica to 50 $\mu g/m^3$ averaged over an 8-h shift.[48] This rule requires employees to regularly monitor crystalline silica through routine sampling, to use engineering controls to limit dust exposure, and to provide medical exams to monitor highly exposed workers by having an action rule at exposure levels of 25 $\mu g/m^3$ averaged over an 8-h shift.[48] In 2014, MSHA also introduced new regulations lowering the PEL for respirable coal mine dust including silica to 1.5 $mg/m^3$ from the previous value of 2 $mg/m^3$. The PEL would be lowered according to a formula if the percentage of silica in dust samples was greater than 5%.[49]

The observed increase in odds of chronic bronchitis, emphysema, and COPD among extraction workers compared to office-related occupations highlights the continued need for dust regulations and enforcement in the mining industry.

This analysis is subject to several limitations based on the data source. First, the NHIS database is based on personal interviews and is therefore subject to recall bias and under- or over-estimation of prevalence due to unfamiliarity with terms used to determine presence or absence of diseases. The definition of emphysema and chronic bronchitis in the study may have introduced some non-differential and differential misclassification: (i) variability in the physician's use of the terms “emphysema” and “chronic bronchitis” may have led to some non-differential misclassification and (ii) The physician's knowledge of the miner's occupational history has a potential to introduce differential misclassification. Misclassification of the type of COPD may have resulted in overestimation of the relationship with emphysema or underestimation of the relationship with chronic bronchitis. However, we continued to see a strong relationship between occupation and COPD which combines both emphysema and chronic bronchitis. Moreover, it is unclear whether diagnosis of emphysema was based on radiology, lung function, or other methods.

Second, the primary question on occupation and industry is based on employment the week prior to the interview, although there are additional questions that gather information on duration of employment in the current job. In this analysis, more that 40% of individuals who were employed in the mining industry the week prior to the interview had mining as their longest held job. Finally, we do not have any information on exposures from other occupations from past employment, environments where individuals reside or visit, or other recreational activities they might be involved in.

## 5 | CONCLUSION

This analysis of US mining industry workers from 2006 to 2015, found that extraction workers had significantly increased odds of chronic bronchitis, emphysema, and COPD compared to low risk mining occupations such as office work. These results strengthen evidence of the association between occupations associated with significant mineral dust exposure and the development of OLD. Analyses that focus on industry alone might miss this important relationship since industry groupings include many occupations with lesser exposures. Our findings support recent regulatory efforts to require lower permissible exposure limits for mineral dust in the mining industry, especially for extraction workers.

## AUTHORS' CONTRIBUTIONS

SM was directly involved with the study concept and design, data acquisition, statistical analysis, and drafting and editing of the manuscript. SM had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. LF was involved with the study concept and design, the statistical analysis, and drafting and editing of the manuscript. RC and KA were involved with the study concept and design, and drafting and editing of the manuscript.

## ACKNOWLEDGMENT

None.

## FUNDING

The research and researchers were supported in part by the National Institute for Occupational Safety and Health (NIOSH) Training Program Grant # T42/OH008672.

## ETHICS APPROVAL AND INFORMED CONSENT

The National Health Interview Survey (NHIS) is a publicly available de-identified annual cross-sectional survey of non-institutionalized Americans. The National Center for Health Statistics (NCHS) collects the data; informed consent is obtained from all individuals and the NCHS Research Review Board approves each years' study protocol.

## DISCLOSURE (AUTHORS)

The authors declare no conflicts of interest.

## DISCLOSURE BY AJIM EDITOR OF RECORD

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

## DISCLAIMER

None.

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**How to cite this article:** Mabila SL, Almberg KS, Friedman L, Cohen R. High exposure mining occupations are associated with obstructive lung disease, National Health Interview Survey (NHIS), 2006-2015. *Am J Ind Med*. 2018;61:715–724. https://doi.org/10.1002/ajim.22890