Assessment of the Respiratory Health of Working US Coal Miners Since 2014—Radiography, Spirometry, and Symptom Assessments

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Objective: The aim of the study is to summarize Coal Workers' Health Surveillance Program findings since 2014, focusing on prevalence of radiographic pneumoconiosis and abnormal spirometry by region. **Methods:** Analysis included the most recent Coal Workers' Health Surveillance Program encounter for working miners during October 1, 2014–June 30, 2022. Central Appalachia consists of Kentucky, Virginia, and West Virginia. **Results:** Pneumoconiosis prevalence was highest among underground miners, with 318 (6.2%) having radiographic evidence of disease. Central Appalachian miners were more likely to have evidence of pneumoconiosis (relative risk = 4.1 [3.4—5.0]) and abnormal spirometry (relative risk = 1.4 [1.2—1.6]) compared with all others. **Conclusions:** Central Appalachia is a hotspot for pneumoconiosis, as well as for other indicators of respiratory impairment in coal miners. Outreach for occupational respiratory health surveillance should focus on those areas most heavily affected, ensuring that miners are not hindered by perceived or actual barriers to this secondary intervention.

Keywords: surveillance, respiratory health, spirometry, pneumoconiosis

LEARNING OUTCOMES

- Discuss the impact of including surface and contracted coal miners in respiratory health screenings aimed at identifying pneumoconiosis
- Identify at least two reasons why coal miners in Central Appalachia may be less likely to participate in voluntary respiratory health screenings intended to protect their health

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The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.
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Findings from the National Institute for Occupational Safety and Health (NIOSH)–administered Coal Workers' Health Surveillance Program (CWHSP) have demonstrated an ongoing increase in prevalence and severity of coal workers' pneumoconiosis since the late 1990s, particularly in Central Appalachia.[1–5] In 2014, the Mine Safety and Health Administration (MSHA) published a final rule (MSHA dust rule) to the Federal Register for the purpose of reducing occupational lung disease in US coal miners. This regulation lowered exposure limits to respirable coal mine dust, extended medical screening to include surface and contract coal miners, and expanded medical surveillance requirements to add periodic lung function testing (spirometry) and a respiratory health questionnaire to the periodic chest radiographic examinations.[6] NIOSH subsequently updated its standards to incorporate these expanded screening requirements.[7,8]

Extending respiratory screenings to surface miners is important as surface miners are known to be at risk for pneumoconiosis with some job types having similar or greater risk for injurious exposures to respirable dust than underground miners.[9–11] This expansion approximately doubled the population of coal miners eligible for respiratory health screenings through the CWHSP. The addition of periodic pulmonary function testing to the radiographic component of the program was significant as spirometry can identify pulmonary impairment not visible on radiographs and in combination with self-reported symptoms and diagnoses provide a more complete picture of respiratory health.[12]

The goal of providing medical examinations to coal miners is to inform miners of their health status, identify respiratory impairment or pneumoconiosis early, and provide miners with pneumoconiosis the opportunity to work in a lower dust environment while retaining their employment.[13,14] However, recent findings demonstrate that the systems and policies in place to achieve these objectives are falling short.[15,16] In 2018, Blackley et al.[17] described the largest cluster of progressive massive fibrosis reported in the scientific literature. This large cluster including both former and working coal miners was identified through a clinic-based investigation, not through the CWHSP, highlighting gaps in public health surveillance. The authors emphasized the importance of the expanded health surveillance in the 2014 MSHA rule and noted that enhanced and continued surveillance would be required to determine the effectiveness of the 2014 dust rule. To that end, this report presents the first comprehensive analysis of the radiography, spirometry and symptom assessments in underground, surface, and contract miner participants of the CWHSP since promulgation of the 2014 MSHA dust rule.

METHODS

Data were restricted to the most recent CWHSP encounter for working underground, surface, and contract coal miners during October 1, 2014–June 30, 2022. Examinations are mandatory for coal miners within their first 30 days of employment and within 3 years of their initial respiratory health screening, and voluntary for the remainder of their career, as described elsewhere. Miners were defined as surface, contract, or underground coal miners based on their employer at the time of examination. Contractors are employed through third-party employers, not employed directly by the mine, and they may work at

either an underground or a surface mine. Contractors were treated as a separate group and were not included in the underground or surface miner count. For regional analyses, Central Appalachia refers to Kentucky, Virginia, and West Virginia. Relative risk (RR) was calculated using the proportion of miners with the outcome of interest by region, comparing Central Appalachia to all other states.

Chest radiographs were classified by NIOSH-certified B Readers according to the International Labour Office standards.[18] Presence of pneumoconiosis was defined by radiographic classifications of small opacity profusion 1/0 or greater. Progressive massive fibrosis (PMF) was defined as presence of at least one large opacity (>1 cm in diameter). Pneumoconiosis is considered a disease of long latency; therefore, analysis of radiographic disease prevalence was restricted to miners with 10 or more years of tenure.

Spirometry results were interpreted using American Thoracic Society/European Respiratory Society 2005 guidelines.[19] Reference equations derived from data collected during NHANES III, using age, sex, height, and self-reported race/ethnicity were used to predict the lower limit of normal (LLN) for spirometry results.[20] Spirometry test results that did not meet the minimum acceptable quality (at least two acceptable maneuvers with the two largest volumes repeatable within 250 mL) were excluded from analysis.[21] Analysis of spirometry test results was restricted to those miners with tenure of at least 1 year. Forced expiratory volume in 1 second (FEV_1) and forced vital capacity (FVC) were used in establishing respiratory disease pattern present, as previously described.[22] Patterns of respiratory impairment were defined as follows:

Obstructive: $FEV_1/FVC < LLN$ and $FVC > LLN$ and $FEV_1 < LLN$;
Restrictive: $FEV_1/FVC > LLN$ and $FVC < LLN$;
Mixed: $FEV_1/FVC < LLN$ and $FVC < LLN$.

If any of the previously mentioned patterns were identified, the spirometry test was classified as abnormal, and if none were identified, it was classified as normal.

The respiratory health assessment administered to coal workers included questions related to respiratory symptoms, such as presence of wheezing, shortness of breath, and chronic cough (coughing on most days for 3 or more months of the year). Health assessment results are presented for those miners with tenure of at least 1 year. Miners were also asked to report if they had ever been told by a doctor, nurse, or other health professional that they have chronic obstructive pulmonary disease (COPD), chronic bronchitis, or emphysema.

Analysis, including χ^2 tests comparing prevalence of disease by region, was completed in SAS 9.4 (Cary, NC). The STrengthening the Reporting of OBservational studies in Epidemiology guidelines for reporting observational studies were followed (Supplemental Digital Content, http://links.lww.com/JOM/B444).[23]

RESULTS

Of the 35,457 working coal miners who participated in the CWHSP during the study period, 13,679 (38.6%) were surface miners, 11,641 (32.8%) were underground miners, and 10,137 (28.6%) were contractors (Table 1). Most participants were males (94.5%) with a median age of 35 years (range, 18–96 years) and a median tenure of 3 years (0–60 years).

Pneumoconiosis prevalence was highest among underground miners with 10 or more years of tenure ($n = 5125$), with 318 (6.2%) having radiographic evidence of disease, including 47 (0.92%) cases of the most severe form, PMF. Among the 4844 surface miners with 10 or more years of tenure, 128 (2.6%) had evidence of pneumoconiosis, including 17 cases (0.35%) of PMF. Among the 1233 contractors with 10 or more years of tenure, 37 (3.0%) had evidence of pneumoconiosis, including 2 cases (0.16%) of PMF.

Spirometry tests meeting acceptability and repeatability criteria were submitted for 6834 miners with 1 or more years of mining tenure. Abnormal spirometry was identified in 377 of 3172 (11.9%) underground miners, 410 of 3116 (13.2%) surface miners, and 81 of 546 (14.8%) contract miners. Among all miners with abnormal spirometry, the restrictive pattern of impairment was most common (558, 8.2%), followed by the obstructive pattern (242, 3.5%) and mixed (68, 1.0%). The mean percent predicted FEV_1 for underground miners was 95.6 (standard deviation [SD] = 13.6), 95.4 (SD = 13.8) for surface miners, and 94.0 (SD = 13.1) for contract miners.

Completed respiratory health assessments were submitted for 8113 miners with at least 1 year of tenure. The most common respiratory symptoms reported by miners were shortness of breath (2062, 25.7%), bringing up phlegm (1735, 21.6%), wheezing or whistling in the chest (1696, 21.1%), and frequent coughing (1552, 19.3%), with 35.2% of miners reporting two or more respiratory symptoms

TABLE 1. Demographics of Participating Miners by Type, October 1, 2014–June 30, 2022

	Total ($N = 35,457$)	Underground ($n = 11,641$)	Surface ($n = 13,679$)	Contractors ($n = 10,137$)
Female, *n* (%)	1,954 (5.5%)	264 (2.3%)	1,092 (8.0%)	598 (5.9%)
Male, *n* (%)	33,503 (94.5%)	11,377 (97.7%)	12,587 (92.0%)	9,539 (94.1%)
Age, median (range)	35 (18–96)	36 (18–94)	39 (18–96)	30 (18–94)
Tenure, median (range)	3 (0–60)	8 (0–51)	4 (0–60)	0 (0–53)
Radiographs[a]	11,202	5,125	4,844	1,233
CWP*	483 (4.3%)	318 (6.2%)	128 (2.6%)	37 (3.0%)
PMF*	66 (0.59%)	47 (0.92%)	17 (0.35%)	2 (0.16%)
Spirometry[b]	6,834	3,172	3,116	546
Abnormal	868 (12.7%)	377 (11.9%)	410 (13.2%)	81 (14.8%)
Obstructive	242 (3.5%)	108 (3.4%)	117 (3.8%)	17 (3.1%)
Restrictive	558 (8.2%)	244 (7.7%)	258 (8.3%)	56 (10.3%)
Mixed	68 (1.0%)	25 (0.8%)	35 (1.1%)	8 (1.5%)
% Predicted FEV_1, mean (SD)	95.4 (13.7)	95.6 (13.6)	95.4 (13.8)	94.0 (13.1)
Respiratory Health Assessments	8,113	3,709	3,713	691
Reported COPD, emphysema, or chronic bronchitis diagnosis	352 (4.3%)	170 (4.6%)	151 (4.1%)	31 (4.5%)
2 or more symptoms[c]	2,852 (35.2%)	1,583 (42.7%)	1,120 (30.2%)	149 (21.6%)

COPD, chronic obstructive pulmonary disease; CWP, coal workers' pneumoconiosis; FEV_1, forced expiratory volume in 1 second; PMF, progressive massive fibrosis.
[a]Radiographs submitted among those miners with 10 or more total years of reported coal mining tenure.
[b]Spirometry tests submitted among those miners with 1 or more years of reported coal mining tenure.
[c]Respiratory disease symptoms include the following: wheezing, cough, shortness of breath, coughing up phlegm, or asthma, COPD, chronic bronchitis, and emphysema diagnosis

TABLE 2. Respiratory Health Conditions and Symptoms for Participating Miners by Region, October 1, 2014–June 30, 2022

	Central Appalachia (n = 7,787)	Noncentral Appalachia (n = 27,670)	RR (95% CI)	P
Radiographs[a]	3,878	7,324		
CWP*	331 (8.5%)	152 (2.1%)	4.1 (3.4–5.0)	<0.0001
PMF*	52 (1.3%)	14 (0.2%)	1.7 (0.9–3.0)	0.06
Spirometry[b]	1,725	5,109		
Abnormal	275 (15.9%)	593 (11.6%)	1.4 (1.2–1.6)	<0.0001
Obstructive	69 (4.0%)	173 (3.4%)	1.2 (0.9–1.6)	0.2
Restrictive	185 (10.7%)	373 (7.3%)	1.5 (1.2–1.7)	<0.0001
Mixed	21 (1.2%)	47 (0.9%)	1.3 (0.8–2.2)	0.3
Respiratory Health Assessments[b]	2,173	5,940		
Reported COPD, emphysema, or chronic bronchitis diagnosis	152 (7.0%)	200 (3.4%)	2.1 (1.7–2.6)	<0.0001
2 or more symptoms[c]	1,226 (56.4%)	1,626 (27.4%)	2.1 (1.9–2.2)	<0.0001
BMI—categories	2,156	5,910		
Overweight	685 (31.8%)	1,986 (33.6%)	0.9 (0.9–2.0)	0.1
Obese	1,262 (58.5%)	3,227 (54.6%)	1.1 (1.0–1.1)	0.0006

Central Appalachia refers to Kentucky, Virginia, and West Virginia, while Noncentral Appalachia refers to all other states.

BMI, body mass index; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CWP, coal workers' pneumoconiosis; PMF, progressive massive fibrosis; RR, relative risk.

[a]Radiographs submitted among those miners with 10 or more total years of reported coal mining tenure.

[b]Spirometry tests and respiratory health assessments submitted among those miners with 1 or more years of reported coal mining tenure.

[c]Respiratory disease symptoms include the following: wheezing, cough, shortness of breath, coughing up phlegm, or asthma, COPD, chronic bronchitis, and emphysema diagnosis.

(Table 1) Three hundred fifty-two miners (4.3%) reported having received a diagnosis of COPD or a related disorder (COPD: 188, 2.3%; emphysema: 56, 0.7%; chronic bronchitis: 161, 2.0%).

Of the 35,457 working coal miners who participated in these respiratory health screenings, 7787 participants (22.0%) worked in the Central Appalachian states of Kentucky, Virginia, and West Virginia (Table 2). Among Central Appalachian miners with 10 or more years of experience (n = 3878), 331 (8.5%) had evidence of pneumoconiosis on their chest x-rays, with 52 (1.3%) showing evidence of PMF. Among Central Appalachian miners with at least 1 year of mining tenure, 69 (4.0%) had spirometry results showing an obstructive pattern of impairment and among miners from all other states, 173 (3.4%) also showed an obstructive pattern (RR = 1.2 [0.9–1.6]). Central Appalachian miners were more likely to have evidence of pneumoconiosis (RR = 4.1 [3.4–5.0]) and abnormal spirometry (RR = 1.4 [1.2–1.6]), compared with miners from all other states. Central Appalachian miners were also more likely to report the presence of two or more respiratory disease symptoms (RR = 2.1 [1.9–2.2]) and to report previous COPD, emphysema, or chronic bronchitis diagnosis (RR = 2.1 [1.7–2.6]), compared with miners from all other states.

DISCUSSION

In 2014, important enhancements were made to the long-standing NIOSH-administered CWHSP. This report presents health surveillance findings including radiography, spirometry, and self-reported respiratory symptoms among US coal miners. In summary, our findings demonstrate that significant respiratory disease exists and continues to persist in contemporary, working underground and surface coal miners, as well as miners employed as contractors. A 2010–2011 survey of surface miners reported 2.0% of miners with at least 1 year of tenure had evidence of pneumoconiosis, and a recent report of the first 6 years of surface miner inclusion in the CWHSP showed 1.6% prevalence of pneumoconiosis.[10,24] The current study focuses on prevalence among longer tenured miners (10 or more working years), but the finding of 2.6% pneumoconiosis prevalence among surface miners is comparable with these previous estimates.

This study affirms that Central Appalachia continues to be a hotspot for pneumoconiosis, as well as for other indicators of respiratory impairment and disease in coal miners. Among coal miners with 10 or more years of tenure, miners in Central Appalachia were 4.1 times more likely to have evidence of pneumoconiosis compared with miners in all other regions of the United States (Table 2). Although COPD rates are the highest in Central Appalachian states (West Virginia had the highest rates of COPD across the United States in 2021 [age-adjusted prevalence, 11.4%][25]), 4% of Central Appalachian miners with 1 or more years of tenure had spirometry results showing an obstructive pattern of impairment, comparable with working aged adults in the United States (4.2%).[26] Overall, Central Appalachian miners were more likely to show either an obstructive, restrictive, or mixed pattern of respiratory impairment (15.9%) compared with miners in the remainder of the United States (11.6%, RR = 1.4 [1.2–1.6]) and were more likely to report a prior diagnosis of COPD, emphysema, or chronic bronchitis (RR = 2.1 [1.7–2.6]). Other factors aside from occupational exposures may also influence respiratory impairment in this population. Central Appalachian miners were more likely to be obese compared with miners in the rest of the US (RR = 1.1 [1.0–1.1]), and obesity has been shown to play a role in respiratory impairment[27,28] While smoking status was not available for this analysis, smoking status also may have an impact on respiratory impairment. Adult tobacco use in Central Appalachia, including cigarette smoking, is among the highest in the United States.[29] However, exposure to coal mine dust has been shown to cause COPD, even after controlling for cigarette smoking.[30–33]

This study also brings to light the challenges in ensuring robust participation in the CWHSP for all US miners. The purpose of the CWHSP is to provide access to respiratory health screenings for working coal miners throughout their careers, at no cost to them, to identify disease early and prevent further progression. This program provides the most up-to-date estimation of the respiratory health of the nation's working coal miners. Its success in identifying disease at an early stage relies on participation of the workforce at regular intervals throughout their careers. The CWHSP examinations are mandatory for new miners within the first 30 days of employment, however, continued participation is voluntary, and has historically been low, fluctuating between 25% and 40% for the past 30 years.[16,34]

The CWHSP participation across the workforce was affected by the first years of the COVID-19 pandemic, as this study's timeframe extended through June 2022. Early in the United States' pandemic response, the US Department of Homeland Security's Cybersecurity and Infrastructure Security Agency listed energy and mineworkers as essential critical infrastructure workers.[35] While this allowed for continuity in mining operations and exempted miners from work stoppages, the

pandemic disrupted routine healthcare and occupational health screenings. As a result of necessary restrictions to protect the mining workforce from COVID-19, the number of respiratory health screenings for miners conducted or received by NIOSH during the pandemic declined precipitously compared with previous years. For a comprehensive discussion of the effects of COVID-19 on participation in the CWHSP, see Hall et al. (2023).[16]

Participation in the CWHSP also differed by region. While Central Appalachia accounted for 40%–45% of US coal mining employment annually from 2014 to 2021, only 21.9% of CWHSP participants worked in Central Appalachia (Table 2). Although many factors may influence a miner's decision to participate in these respiratory health screenings, unemployment statistics in Central Appalachia show that unemployment is relatively high in this region (ranging from 2.5% to 3.9% in June 2022), while unemployment in the mining workforce in particular is elevated (2.6% in March 2022 to 6.5% in March 2023).[36]

An environment where unemployment is high and opportunities for other employment in mining are low may lead to fraught decisions for coal miners, who may perceive a respiratory disease determination as a threat to their employment status.[37–39] These workers may elect to not participate in voluntary respiratory health screenings regardless of the ease of access, to prioritize stability and job security in the short term. Faced with a real or perceived lack of adequate job protection, miners continue to work through the beginning stages of disease, increasing their exposure to hazardous levels of coal mine dust and thereby increasing the likelihood of developing more severe and debilitating illness. Miners with radiographic evidence of pneumoconiosis can exercise their right to work in a lower dust position without a reduction in pay. However, recent data show that more than 75% of eligible miners do not participate in this job transfer program.[15]

Although routine medical surveillance and job change or transfer may protect health in the long term, it is clear that some miners avoid critical health screenings and requests for special health protections. Instead, they continue to work in dusty, hazardous conditions with respiratory impairment, often expressing that providing for their family is paramount, even at the cost of their own health.[21,38,40] This report highlights that voluntary participation in respiratory health screening is not working as intended and recent trends in participation seem to track with the trends in overall coal miner employment in the United States. Perhaps of most concern is that the region of the country with the highest prevalence of disease also has the lowest levels of participation in respiratory health surveillance, a program designed specifically to protect their health. It is important to note that these findings also demonstrate that pneumoconiosis continues to occur among contemporary coal miners in the United States despite it being clear that this system has not identified every case of pneumoconiosis among currently employed coal miners. This is an observation that has been borne out from analyses of federal disability compensation data where 39% of miners with disabling pneumoconiosis did not participate in the NIOSH CWHSP during their working careers.[41] While the collective approach to assessing and protecting the respiratory health of the US coal mining workforce can certainly be improved, continued monitoring of respiratory health of actively working coal miners is necessary for early intervention to avoid unnecessary progression to the most advanced stages of pulmonary fibrosis.

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REFERENCES

1. Laney AS, Attfield MD. Coal workers' pneumoconiosis and progressive massive fibrosis are increasingly more prevalent among workers in small underground coal mines in the United States. *Occup Environ Med* 2010;67:428–431.
2. Laney AS, Petsonk EL, Attfield MD. Pneumoconiosis among underground bituminous coal miners in the United States: is silicosis becoming more frequent? *Occup Environ Med* 2010;67:652–656.
3. Blackley DJ, Halldin CN, Laney AS. Resurgence of a debilitating and entirely preventable respiratory disease among working coal miners. *Am J Respir Crit Care Med* 2014;190:708–709.
4. Blackley DJ, Halldin CN, Laney AS. Continued increase in prevalence of coal workers' pneumoconiosis in the United States, 1970–2017. *Am J Public Health* 2018;108:1220–1222.
5. Hall NB, Blackley DJ, Halldin CN, Laney AS. Continued increase in prevalence of r-type opacities among underground coal miners in the USA. *Occup Environ Med* 2019;76:479–481.
6. Department of Labor. *Lowering Miners' Exposure to Respirable Coal Mine Dust, Including Continuous Personal Dust Monitors*, in *30 CFR Parts 70, 71, 72 et al*. Mine Safety and Health Administration; 2014. Available at: https://www.govinfo.gov/content/pkg/FR-2014-05-01/pdf/2014-09084.pdf. Accessed June 23, 2023.
7. Department of Health and Human Services. *U.S. Code of Federal Regulations Interim Final Rule, in 42. Chapter I. Part 37: Specifications for Medical Examinations of Coal Miners*. Centers for Disease Control; 2014. Available at: https://www.govinfo.gov/content/pkg/FR-2014-08-04/pdf/2014-18336.pdf. Accessed June 23, 2023.
8. Reynolds LE, Wolfe AL, Clark KA, et al. Strengthening the coal workers' health surveillance program. *J Occup Environ Med* 2017;59:e71.
9. Doney BC, Blackley D, Hale JM, et al. Respirable coal mine dust at surface mines, United States, 1982–2017. *Am J Ind Med* 2020;63:232–239.
10. Hall NB, Halldin CN, Blackley DJ, Laney AS. Assessment of pneumoconiosis in surface coal miners after implementation of a national radiographic surveillance program, United States, 2014–2019. *Am J Ind Med* 2020;63:1104–1108.
11. Halldin CN, Reed WR, Joy GJ, et al. Debilitating lung disease among surface coal miners with no underground mining tenure. *J Occup Environ Med* 2015;57:62–67.
12. Petsonk EL, Wang ML. Interpreting screening questionnaires: specific respiratory symptoms and their relationship to objective test results. *J Occup Environ Med* 2010;52:1225–1229.
13. Hall NB, Blackley DJ, Halldin CN, Laney AS. Pneumoconiosis progression patterns in US coal miner participants of a job transfer programme designed to prevent progression of disease. *Occup Environ Med* 2020;77:402–406.
14. Reynolds L, Halldin CN, Laney AS, Blackley DJ. Coal miner participation in a job transfer program designed to prevent progression of pneumoconiosis, United States, 1986–2016. *Arch Environ Occup Health* 2018;73:344–346.
15. Laney AS, Hall NB, Reynolds L, et al. Low participation in a job transfer program designed to prevent progression of pneumoconiosis. *Ann Am Thorac Soc* 2023;20:1223–1224.
16. Hall NB, Reynolds L, Blackley DJ, Laney AS. Submission of mandatory respiratory health examinations among US coal miners participating in the Coal Workers' Health Surveillance Program. *Occup Environ Med* 2023;80:327–332.
17. Blackley DJ, Reynolds LE, Short C, et al. Progressive massive fibrosis in coal miners from 3 clinics in Virginia. *JAMA* 2018;319:500–501.
18. International Labour Office. *Guidelines for the use of the ILO international classification of radiographs of pneumoconioses*. Geneva: International Labour Office; 2011.
19. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J* 2005;26:319–338.
20. Hankinson JL, Odencrantz JR, Fedan KB. Spirometric reference values from a sample of the general U.S. population. *Am J Respir Crit Care Med* 1999;159:179–187.
21. Reynolds LE, Blackley DJ, Colinet JF, et al. Work practices and respiratory health status of Appalachian coal miners with progressive massive fibrosis. *J Occup Environ Med* 2018;60:e575–e581.
22. Blackley DJ, Halldin CN, Wang ML, Laney AS. Small mine size is associated with lung function abnormality and pneumoconiosis among underground coal miners in Kentucky, Virginia and West Virginia. *Occup Environ Med* 2014;71:690–694.
23. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 2007;370:1453–1457.
24. Centers for Disease Control and Prevention (CDC). Pneumoconiosis and advanced occupational lung disease among surface coal miners—16 states, 2010–2011. *MMWR Morb Mortal Wkly Rep*. 2012;61(23):431–4.
25. Centers for Disease Control and Prevention National Center for Chronic Disease Prevention and Health Promotion Division of Population Health. BRFSS prevalence & trends data [online]. 2021. Available at: https://www.cdc.gov/brfss/brfssprevalence/. Accessed June 23, 2023.

26. Doney B, Hnizdo E, Syamlal G, et al. Prevalence of chronic obstructive pulmonary disease among US working adults aged 40 to 70 years. National Health Interview Survey data 2004 to 2011. *J Occup Environ Med* 2014;56:1088–1093.
27. Forno E, Han YY, Mullen J, Celedon JC. Overweight, obesity, and lung function in children and adults—a meta-analysis. *J Allergy Clin Immunol Pract* 2018;6:570–581.e10.
28. Melo LC, Silva MA, Calles AC. Obesity and lung function: a systematic review. *Einstein (Sao Paulo)* 2014;12:120–125.
29. Appalachian Research Commission. Issue Brief: Health disparities related to smoking in Appalachia. Creating a Culture of Health in Appalachia; April 2019. Available at: https://www.arc.gov/wp-content/uploads/2020/06/HealthDispairitiesRelatedtoSmokinginAppalachiaApr2019.pdf. Accessed June 23, 2023.
30. Laney AS, Weissman DN. Respiratory diseases caused by coal mine dust. *J Occup Environ Med* 2014;56(suppl 10):S18–S22.
31. Kurth L, Laney AS, Blackley DJ, Halldin CN. Prevalence of spirometry-defined airflow obstruction in never-smoking working US coal miners by pneumoconiosis status. *Occup Environ Med* 2020;77:265–267.
32. Kuempel ED, Wheeler MW, Smith RJ, et al. Contributions of dust exposure and cigarette smoking to emphysema severity in coal miners in the United States. *Am J Respir Crit Care Med* 2009;180:257–264.
33. Seixas NS, Robins TG, Attfield MD, Moulton LH. Exposure-response relationships for coal mine dust and obstructive lung disease following enactment of the Federal Coal Mine Health and Safety Act of 1969. *Am J Ind Med* 1992;21:715–734.
34. Hall NB, Blackley DJ, Halldin CN, Laney AS. Current review of pneumoconiosis among US coal miners. *Curr Environ Health Rep* 2019;6:137–147.
35. US Department of Homeland Security. *Guidance on the Essential Critical Infrastructure Workforce: Ensuring Community and National Resilience in COVID-19 Response, v.4.1. Cybersecurity and Infrastructure Security Agency*, Editor. August 2021. Available at: https://www.cisa.gov/sites/default/files/publications/essential_critical_infrastructure_workforce-guidance_v4.1_508.pdf. Accessed June 23, 2023.
36. Bureau of Labor Statistics, US Department of Labor. Labor Force Statistics From the Current Population Survey. Occupational Outlook Handbook; 2023. Available at: https://www.bls.gov/ooh/home.htm. Accessed May 4, 2023.
37. Benach J, Vives A, Amable M, et al. Precarious employment: understanding an emerging social determinant of health. *Annu Rev Public Health* 2014;35:229–253.
38. Shriver TE, Bodenhamer A. The enduring legacy of black lung: environmental health and contested illness in Appalachia. *Sociol Health Illn* 2018;40:1361–1375.
39. National Institute for Occupational Safety and Health. *Barriers to Participation in the NIOSH Coal Workers Health Surveillance Program, in 83 FR 56327, Centers for Disease Control and Prevention*. National Archives: Federal Register; 2018:56327–56328. Available at: https://www.federalregister.gov/documents/2018/11/13/2018-24700/barriers-to-participation-in-the-niosh-coal-workers-health-surveillance-program. Accessed June 23, 2023.
40. National Institute for Occupational Safety and Health. *Faces of Black Lung II*. 2020. Publication No. 2020–109D. Available at: https://www.cdc.gov/niosh/docs/video/2020-109D/. Accessed June 23, 2023.
41. Almberg KS, Cohen RA, Blackley DJ, et al. Linking compensation and health surveillance data sets to improve knowledge of US coal miners' health. *J Occup Environ Med* 2017;59:930–934.

