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BRIEF REPORT

Prevalence of Reduced Mid-Expiratory Flow Among Coal Workers' Health Surveillance Program Participants

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ABSTRACT

Background: Small airways disease is a risk factor for the development of obstructive lung disease and may be present among coal miners without obstructive ventilatory impairment. Our study estimated the prevalence of reduced spirometric mid-expiratory flow among coal miners without obstructive ventilatory impairment.

Methods: Data were from coal miners participating in the Coal Workers' Health Surveillance Program (CWHSP) during 2014–2022 with forced expiratory volume in the first second (FEV1) and forced vital capacity (FVC) meeting quality criteria and no missing spirometry parameter values. We defined low forced expiratory flow at 25%–75% ($FEF_{25\%–75\%}$) as < 65% predicted.

Results: The prevalence of $FEF_{25\%–75\%}$ < 65% predicted among miners without obstructive ventilatory impairment was 7.1% overall, 10.7% among retired miners, and 16.8% among miners with radiographic evidence of coal workers' pneumoconiosis (CWP).

Conclusions: Among miners without obstructive ventilatory impairment, reduced mid-expiratory flow was more prevalent in older miners with longer tenure, specifically retired miners. From a surveillance perspective, reduced spirometric mid-expiratory flow can be an early indicator of more serious health problems in coal miners, including obstructive lung disease.

1 | Introduction

Inhalation of respirable coal mine dust causes a range of lung diseases and symptoms [1, 2]. The accumulation of coal mine dust particles in the lungs triggers systemic pathophysiologic changes (e.g., airway remodeling, mucus plugging, and immune cell infiltration) that can lead to fibrosis and airflow obstruction [2, 3]. One cause of airflow obstruction is small airways disease, which is characterized by reduced expiratory airflow in the small airways of the lung (airways < 2 mm in diameter). Small airways disease is associated with, and predictive of, obstructive lung diseases including chronic obstructive pulmonary disease (COPD) and asthma [4–8]. Small airways disease is particularly frequent among populations with prolonged inorganic dust exposures, yet has been understudied among coal miners [2, 5, 9].

Currently, there is no gold standard for assessing small airway function noninvasively. Spirometry is one of the more widely available noninvasive approaches used to assess airway function [4, 7, 10]. The spirometric parameter quantifying forced expiratory volume in the first second (FEV1) primarily reflects obstructive abnormalities in the large airways, but the forced mid-expiratory flow ($FEF_{25\%–75\%}$) is often reduced when the

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small airways are obstructed [4, 5, 8, 11]. This parameter reflects the maximum forced expiratory flow between the 25% and 75% intervals of the measured forced vital capacity (FVC). Reduced $FEF_{25\%-75\%}$ is predictive of COPD development when other lung function parameters are normal, even after adjusting for age, smoking history, and FEV1/FVC at baseline [6, 8, 12].

To identify and prevent further progression of lung disease in coal miners, the National Institute for Occupational Safety and Health (NIOSH) administers the Coal Workers' Health Surveillance Program (CWHSP). This program, available to actively-working US coal miners, includes a spirometry test, chest radiograph, and respiratory health assessment at no cost to the miner. Following the 2014 Mine Safety and Health Administration Dust Rule, a CWHSP examination was mandated for all miners new to the coal mining industry within their first 30 days of employment and within 3 years of their initial respiratory health screening. However, participation in the CWHSP is voluntary for the remainder of a miner's career [13]. To help identify coal miners who may go on to develop obstructive lung disease, this study used CWHSP examination data to report the prevalence of reduced mid-expiratory flow among coal miners without obstructive ventilatory impairment by demographic characteristics, mining characteristics, and presence and degree of pneumoconiosis.

2 | Methods

Underground, surface, and contract (employed through a third-party employer and not directly by the mine) coal miners ≥ 18 years of age participating in the CWHSP from August 2014 through December 2022 were included in this analysis. CWHSP examinations were performed either in the NIOSH mobile examination unit that travels to coal mining regions throughout the U.S. or at an approved clinic [14]. For miners with multiple CWHSP examinations, only data from the most recent CWHSP spirometry test were included. Miners are offered the spirometry testing, chest radiograph, and respiratory assessment but may not complete all components.

Spirometry testing was performed following American Thoracic Society and European Respiratory Society (ATS/ERS) guidelines and administered by a technician who completed a NIOSH-approved spirometry training course [11, 15]. Quality spirometry results were those with at least two acceptable maneuvers and repeatability of the largest two volumes within 250 mL and that included no missing FEF25, FEF75, FEV1, and FVC values [11]. At the time of spirometry testing, miners reported their age, sex, and race. Spirometry results identified miners with evidence of an obstructive ventilatory impairment defined per ATS/ERS criteria as FEV1/FVC below the lower limit of normal (LLN) [16]. Normative reference equations developed from the Third National Health and Nutrition Examination Survey (NHANES III) data were used to determine predicted and LLN pulmonary function values [17]. Miners with evidence of obstructive ventilatory impairment from spirometry were excluded from this analysis so we could evaluate early airways dysfunction. Among the miners without an obstructive pattern, possible small airways dysfunction was identified by reduced mid-expiratory flow, defined as $FEF_{25\%-75\%} < 65\%$ predicted [12].

Chest radiographs were classified by at least two NIOSH-certified B Readers according to the International Labour Office (ILO) system [18]. Coal workers' pneumoconiosis (CWP) was defined by a radiographic classification of small opacity profusion of subcategory 1/0 or greater and further classified using major category scales (1, 2, 3). Among those with CWP, progressive massive fibrosis (PMF) was defined as the presence of at least one large opacity (> 1 cm in diameter) [18].

As part of the CWHSP intake process, miners self-reported their mining tenure. Miners reporting tenure solely in surface mines were classified as "Surface only" miners, and those reporting tenure solely in underground mines were classified as "Underground only" miners. Miners reporting tenure in both surface and underground mines were therefore classified as "Both surface and underground miners." Miners reporting 0 years of mining tenure were classified as "New miners" (new to the coal mining industry), and those no longer working in mining were classified as "Retired miners." Mining regions were identified based on the state where a miner worked at the time of the most recent CWHSP encounter, with regions defined as eastern (Maryland, Ohio, Pennsylvania, Tennessee), central Appalachian (Kentucky, Virginia, West Virginia), interior (Arkansas, Illinois, Indiana, Iowa, Louisiana, Mississippi, Oklahoma, Texas), and western (Arizona, Alaska, Colorado, Montana, New Mexico, North Dakota, Utah, Washington, Wyoming).

The respiratory assessment form contains questions on self-reported clinician-diagnosed respiratory disease including COPD (COPD, chronic bronchitis, or emphysema) and asthma as well as respiratory symptoms: presence of wheezing, chronic cough (coughing on most days for 3 or more months of the year), shortness of breath, and coughing up phlegm. This form also collected information about smoking status.

Statistical analyses were completed in SAS V 9.4 (SAS Institute Inc., Cary, NC). Frequencies of demographic, mining, and respiratory characteristics, reduced mid-expiratory flow, and pneumoconiosis were calculated for coal miners. Pearson's χ^2 tests were used to compare low $FEF_{25\%-75\%}$ by demographic characteristics and presence of CWP, and were considered significant at p value < 0.05 ($p < 0.05$).

3 | Results

From August 2014 through December 2022, 11,898 spirometry tests were submitted to the CWHSP. For miners with multiple spirometry tests, we selected the most recent test ($n = 11,440$). Of these, 8464 (74%) spirometry tests met quality criteria (Figure 1). We excluded 848 (10.0%) tests with obstructive ventilatory impairment, resulting in data from 7616 miners for this study [11]. Among the 7616 included miners were 711 miners with a restrictive pattern of ventilatory impairment (FEV1/FVC > LLN and FVC < LLN).

The prevalence of $FEF_{25\%-75\%} < 65\%$ predicted among the 7616 miners was 7.1%. Reduced mid-expiratory flow was significantly associated with age ($p < 0.00001$), and the prevalence increased with age from 3.5% in miners < 40 years of age to 9.3% in miners 50–59 and 10.5% in miners ≥ 60 years of age. Reduced

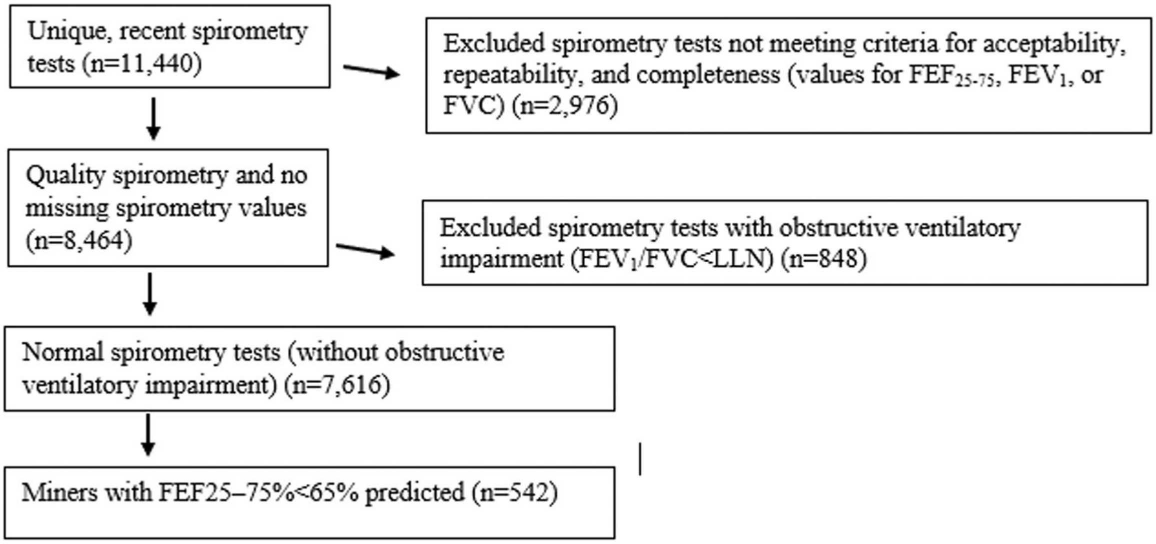

FIGURE 1 | Spirometry tests from CWHSP examinations August 2014–December 2022.

mid-expiratory flow was significantly associated with smoking ($p < 0.0001$), and the prevalence among ever-smokers was 9.1% (vs. 5.9% among never-smokers).

Among the 7616 miners, 7121 had both a spirometry test and a corresponding chest radiograph completed within 30 days of the submitted spirometry test. For these 7121 miners, additional respiratory and mining characteristics were available (Table 1). The prevalence of $FEF_{25\%-75\%} < 65\%$ predicted was 4.6% among 829 new miners and 10.7% among 1310 retired miners. Among the remaining 4982 working miners, the prevalence of low $FEF_{25\%-75\%}$ was 10.1% among miners with ≥ 25 years of total mining tenure. The highest prevalence of $FEF_{25\%-75\%}$ below 65% predicted was in miners working in the eastern (8.5%) and central Appalachia (8.3%) mining regions.

Low $FEF_{25\%-75\%}$ was seen in 17.2% of miners reporting COPD and in 12.3% of miners reporting asthma. Prevalence was higher among miners reporting respiratory symptoms, including wheezing (13.8%), chronic cough (10.5%), shortness of breath (10.4%), and coughing up phlegm (9.4%) than in the overall sample (7.1%).

$FEF_{25\%-75\%}$ below 65% predicted was significantly associated ($p < 0.00001$) with CWP (16.8%). The prevalence of low $FEF_{25\%-75\%}$ among those with Category 1 profusion was 17.9%, 14.1% in miners with Category 2 profusion, and 19.2% in those with PMF. Of the 848 excluded spirometry tests in miners with obstructive impairment, 738 (87%) had evidence of reduced mid-expiratory flow. In addition, of 711 miners with a restrictive pattern of ventilatory impairment, 165 (23%) had evidence of reduced mid-expiratory flow.

Reduced mid-expiratory flow was significantly associated with smoking ($p < 0.0001$), and the prevalence among ever-smokers was 9.1% (vs. 5.9% among never-smokers). Among ever-smokers, the prevalence of reduced mid-expiratory flow was highest among those aged ≥ 60 (13.3%), females (16.2%), retired miners (13.8%), miners with ≥ 25 years of total mining tenure (13.3%), miners in central Appalachia (11.2%), and those with self-reported COPD (20.3%) and wheezing (16.1%).

4 | Discussion

Reduced mid-expiratory flow, as evident by $FEF_{25\%-75\%}$ spirometric values $< 65\%$ predicted, may be suggestive of possible small airways dysfunction and potentially early airflow obstruction [3, 6, 12]. Among participating coal miners without obstructive ventilatory impairment, 7.1% had $FEF_{25\%-75\%}$ values below 65% predicted. However, the reliability of spirometry parameters may be affected by the miner's effort, ability to perform spirometry, and recent cold, flu, respiratory infection, or inhalation of particulates. Therefore, $FEF_{25\%-75\%}$ should not be used for clinical decision making as it is highly dependent on the validity of the FVC measurement and related to expiratory effort [6, 10, 16]. Furthermore, mid-expiratory flow is not specific to changes in the small airways and may indicate abnormal lung function at other parts of the lung [7]. Assessing small airways dysfunction is difficult, and there is no single acceptable approach and often more than one approach should be considered (e.g., body plethysmography, impulse oscillometry, nitrogen washout, or lung imaging) [3, 7, 12].

From a surveillance perspective, small airways dysfunction can be an early indicator of more serious impending lung function problems among coal miners. Underground coal miners experiencing rapid lung function decline had significantly lower $FEF_{25\%-75\%}$ flow rates compared to referent miners [9]. Air trapping and airway resistance in the small airways were identified as the mechanisms for accelerated lung function decline [9]. Another indicator of impending lung function problems could be reported symptoms. Miners in this study without obstructive ventilatory impairment but with $FEF_{25\%-75\%} < 65\%$ predicted reported respiratory symptoms. Reduced mid-expiratory flow was more prevalent in older miners with longer tenure, specifically retired miners. However, it is important to note that age and tenure are linked, with age often used as a proxy for tenure, and vice versa.

Small airways dysfunction is also a ventilatory abnormality identified in those with CWP. The accumulation of coal mine dust particles in the lungs causes inflammation and fibrosis

TABLE 1 | $FEF_{25\%-75\%} < 65\%$ predicted among Coal Workers' Health Surveillance Program coal miners without obstructive ventilatory impairment, August 2014–December 2022.

Characteristics	Number in sample (*N*)	Prevalence of $FEF_{25\%-75\%} < 65\%$ predicted *n* (%)		
		Overall	Ever smoker[a] (*n* = 2889)	Never smoker (*n* = 4599)
Total	7616	542 (7.1)	264 (9.1)*	270 (5.9)
Age, median (range)	48 (18–91)	56 (18–85)	57 (18-80)	56 (20–85)
Age group (years)				
< 40	2626	92 (3.5)*	41 (3.9)	39 (2.6)
40–49	1420	94 (6.6)	38 (7.6)	46 (5.1)
50–59	1547	144 (9.3)	65 (12.0)	69 (7.1)
≥ 60	2023	212 (10.5)	105 (13.3)	95 (7.9)
Sex				
Male	7343	518 (7.0)	248 (8.9)	262 (5.9)
Female	273	24 (8.8)	16 (16.2)	8 (4.7)
Race				
White	6682	488 (7.3)	228 (8.8)	218 (5.5)
Other	934	54 (5.8)	21 (7.1)	31 (4.9)
Miner type[b]				
New Miners	829	38 (4.6)	22 (6.2)	16 (3.4)
Surface only miners	2255	146 (6.5)	75 (8.8)	71 (5.1)
Underground only miners	2075	125 (6.0)	59 (8.2)	61 (4.8)
Both surface and underground miners	652	57 (8.7)	19 (8.2)	37 (9.0)
Retired miners	1310	140 (10.7)	74 (13.8)	64 (8.4)
Total mining tenure (years)[b]				
0 (new miner)	829	38 (4.6)	22 (6.2)	16 (3.4)
> 0– < 10	1766	79 (4.5)	42 (5.9)	35 (3.4)
10–25	2272	162 (7.1)	83 (9.6)	76 (5.6)
≥ 25	2254	227 (10.1)	102 (13.3)	122 (8.4)
Mining region[b]				
Central Appalachia	2214	183 (8.3)	89 (11.2)	89 (6.5)
Eastern	1041	89 (8.5)	40 (10.8)	46 (7.6)
Interior	1811	125 (6.9)	71 (9.1)	54 (5.3)
Western	2055	109 (5.3)	49 (6.5)	60 (4.6)
Self-reported respiratory disease[c]				
COPD	343	59 (17.2)	37 (20.3)	22 (13.7)
Asthma	536	66 (12.3)	26 (13.3)	35 (11.6)
Self-reported respiratory symptoms[d]				
Wheezing	1591	219 (13.8)	113 (16.1)	95 (11.7)
Chronic cough	1540	162 (10.5)	90 (13.8)	65 (8.1)
Shortness of breath	2195	228 (10.4)	121 (13.8)	98 (8.0)
Coughing up phlegm	1731	162 (9.4)	84 (11.4)	68 (7.6)
No CWP (Category 0)[b]	6859	462 (6.7)	226 (8.8)	230 (5.5)
CWP[b,e]	262	44 (16.8)	23 (19.2)	19 (13.7)

(Continues)

TABLE 1 | (Continued)

Characteristics	Number in sample (N)	Prevalence of $FEF_{25\%-75\%} < 65\%$ predicted n (%) Overall	Ever smoker[a] ($n = 2889$)	Never smoker ($n = 4599$)
Category 1 profusion	184	33 (17.9)	16 (18.4)	15 (16.0)
Categories 2–3 profusion	78	11 (14.1)	7 (21.2)	—
PMF	26	5 (19.2)	—	—

[a]Smoking status missing for 128 miners.
[b]Miner type, mining tenure, miner region, and CWP results missing for 495 miners.
[c]Self-reported respiratory disease missing for 199 miners without obstructive ventilatory impairment and for 13 miners with $FEF_{25\%-75\%} < 65\%$ predicted. COPD includes self-reported COPD, chronic bronchitis, or emphysema.
[d]Self-reported respiratory symptoms missing for [at most] 205 miners without obstructive ventilatory impairment and for 11 miners with $FEF_{25\%-75\%} < 65\%$ predicted.
[e]Results suppressed due to small sample size ($n < 5$).
*Significant p value ($p < 0.05$) based on Pearson's χ^2 tests.

affecting both the large and small airways. Our study indicated that among miners without obstructive ventilatory impairment, 16.8% with CWP had reduced mid-expiratory flow. In a study of patients at a Turkish occupational clinic with any type of pneumoconiosis, small airways dysfunction (defined as at least two of FEF50%, FEF75%, and $FEF_{25\%-75\%}$ measurements < 65% predicted) was present in 47.7% of pneumoconiosis patients overall, in 41.5% of patients with airflow obstruction, and in 75.3% of patients reporting a mining occupation [19]. The prevalence of small airways dysfunction increased significantly as the ILO small opacity profusion category progressed [19].

While decreased $FEF_{25\%-75\%}$ is predictive of obstructive impairment among high-risk individuals, this was a cross-sectional study, and we were unable to monitor disease progression over time. We lacked post-bronchodilator spirometry measurements for assessment of asthma as well as other clinical tests (e.g., oscillometry, multiple-breath washout, or imaging tests) which would reduce the likelihood of misdiagnosed obstructive lung disease [10].

Participation in the CWHSP is only mandatory for those coal miners new to the industry, though not all miners receive these mandatory examinations [13]. As participation in the CWHSP is voluntary for much of a miner's career, the prevalence of low $FEF_{25\%-75\%}$ in this study may not be representative of the prevalence for all miners. In addition, nearly 3000 participating miners were excluded from the study due to either poor quality or missing spirometry values. Our study included only high-quality spirometry data and chest radiographs.

It is important that efforts to prevent the development of small airways disease among working coal miners focus on reducing exposure to occupational and environmental hazards, such as respirable coal mine dust. Approximately half of the miners with reduced $FEF_{25\%-75\%}$ < identified in this analysis were smokers, and smoking also contributes to small airways disease [5]. The high prevalence among smokers highlights the value of providing smoking cessation resources to miners who smoke [5].

5 | Conclusions

Monitoring and understanding lung function in coal miners is especially important as coal mine dust particles in the lungs can lead to airflow obstruction and other forms of ventilatory impairment. While small airways disease can be preventable and is treatable, we found that $FEF_{25\%-75\%}$ less than 65% predicted is prevalent in longer tenure, older miners and in miners with CWP. To better understand the prevalence of reduced forced mid-expiratory flow prior to the development of obstructive ventilatory impairment among coal miners, we excluded miners with evidence of an obstructive ventilatory impairment. Decreased $FEF_{25\%-75\%}$ can be an early indicator of more serious impending ventilatory impairment among coal miners and can help identify working miners that could benefit from early detection, intervention, or continued monitoring to prevent progression to preventable lung disease.

Author Contributions

Laura Kurth and Noemi B. Hall participated in the conception and design of the work; Noemi B. Hall was responsible for the acquisition of data and analysis of data; Laura Kurth led the writing of the work; Laura Kurth, Noemi B. Hall, Brian Ansell, A. Scott Laney, and David J. Blackley participated in the interpretation of data for the work, revised drafts of the work, and provided the final approval of this article to be published and agree to be accountable for all aspects of the work.

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Disclosure

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention. Mention of any company or product does not constitute endorsement by the National Institute for Occupational Safety and Health, Centers for Disease Control and Prevention.

Ethics Statement

The Coal Workers' Health Surveillance Program (CWHSP) is a surveillance program. This activity was reviewed by CDC, deemed not-research, and was conducted consistent with applicable federal law and CDC policy.

Conflicts of Interest

The authors declare no conflicts of interest.

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